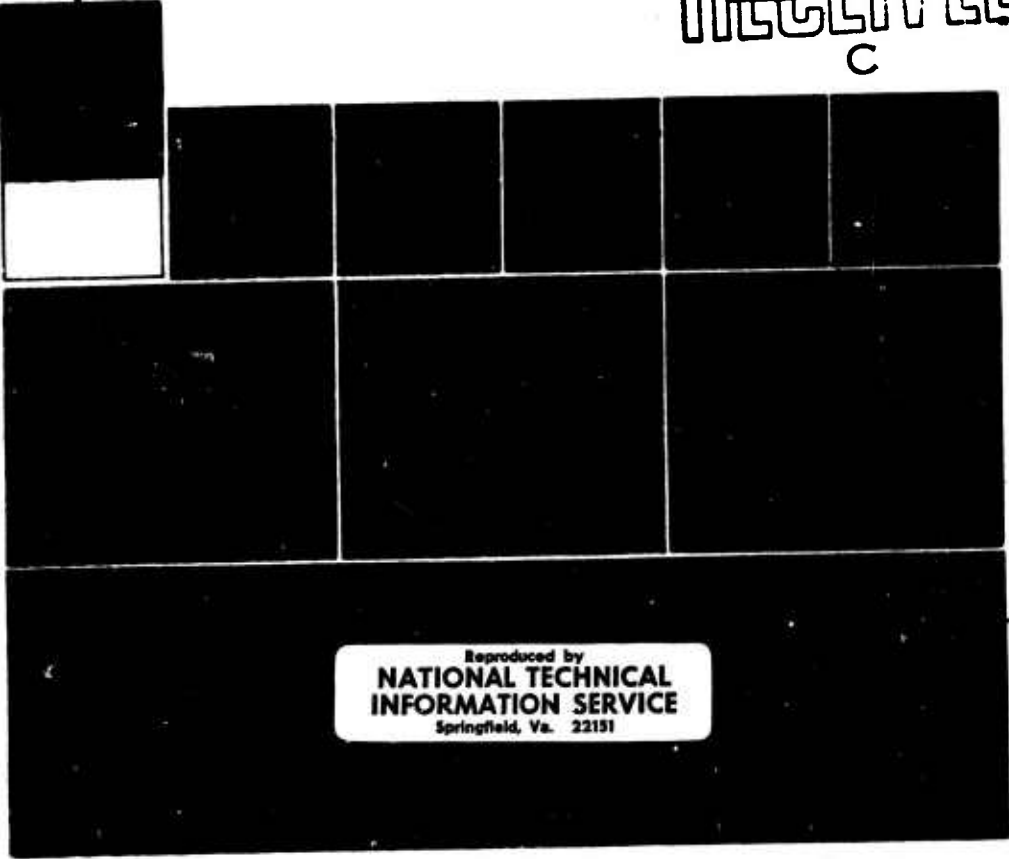


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study on potential use of
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for the department of the army

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**STUDY ON THE POTENTIAL USE OF INDUSTRIALIZED
BUILDING FOR THE DEPARTMENT OF THE ARMY**

VOLUME II: NARRATIVE

By

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August 1971

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FORWARD

The investigation of the potential use of industrialized Building for the Department of the Army was performed by the Construction Engineering Research Laboratory (CERL) under the direction of the Directorate of Military Construction, Office of the Chief of Engineers (OCE). The work was performed under a reimbursable work order NAM-M-71-141 from OCE.

CERL personnel directly concerned with this study were Dr. D. Gordon Bagby, Dr. Robert M. Dinnat, Prof. Christopher A. Moyer, Robert Neathammer, and William J. Pananos.

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The Office of the Chief of Engineers monitor was William E. Johnson (Directorate of Military Construction, Engineering Division, Structures Branch).

ABSTRACT

Study Objectives

This study had six principal objectives.

1. To provide background information on the history, characteristics and direction of industrialized building;
2. To measure and document the present capabilities of the industrialized building;
3. To identify industrialized building systems suitable for employment in the Army's military construction program;
4. To suggest locations where industrialized building is likely to be most economical;
5. To identify and discuss possible procurement and implementation procedures; and
6. To provide comparisons between conventional and industrialized construction costs and construction durations.

The primary sources of industrialized building data were mail surveys conducted during the period March 15 to May 15 inclusive.

Six hundred and sixty-four individual industrialized building manufacturer/supplier firms were identified and queried. Forty-seven percent responded.

Each firm was judged on its ability to provide a feasible alternative to conventional building. That is, the concern's product had to be:

1. Design compatible (capable of meeting the DOD construction criteria);
2. Production compatible (capable of successfully competing against conventional building); and
3. Procurement compatible (capable of being procured under existing Armed Services Procurement Regulations).

Design compatibility was determined by comparing the DOD construction standards with the building characteristics of a firm's product.

Production compatibility was determined by: Firstly, aggregating the Army's building program into 82, spatially distributed, planned construction zones of 50 mile radius; secondly, locating each firm geographically and establishing its radius of maximum economic product shipping distance, or market area; thirdly, identifying the planned construction zones falling within each firm's economical shipping radius; and fourthly, comparing a firm's minimum acceptable production volume with the programmed military construction volume in that the firm's market area.

Procurement compatibility was determined by comparing a firm's contracting procedures to ASPR.

Several important findings emerged from this study. Only 24 firms within the continental United States evidenced the requisite design, procurement policies, and production capabilities to meet immediate military construction needs. An additional 25 firm products were suitable for use in selected building types in particular geographical regions. Secondly, joint purchasing consortiums with some civilian agencies proximate to military installations are possible during the intermediate range MCA Program. Thirdly, cost comparisons with conventional construction proved inconclusive. Finally, substantial construction time savings will accompany the introduction of industrialized methods in military building programs.

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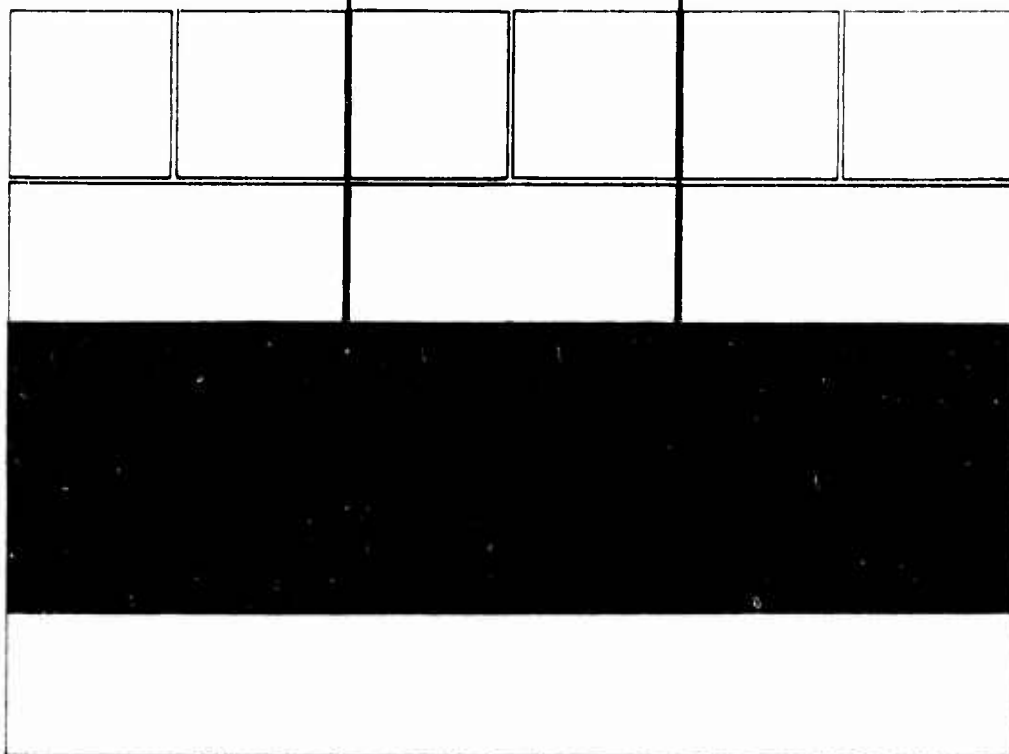
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introduction
1

PURPOSE

The portent for the future of this Nation's construction industry is one of rapidly increasing construction costs combined with rigid or slowly rising construction budgets. As a consequence of these foreboding trends, building buyers are considering several alternatives to current construction methods. Industrialized building is one such alternative and, judging from the publicity it has received, the most promising. The U. S. Army's Construction Engineering Research Laboratory (CERL) was directed by the Office of the Chief of Engineers (OCE), to study the use of industrialized building as a feasible alternative to conventional building on Army installations in the continental United States (CONUS). This document describes the results of that investigation.

STUDY GOALS

The study had six principal goals:

1. To provide background information on the history, characteristics and direction of industrialized building;
2. To measure the present capabilities of the industrialized building industry and assess its probable response to programmed military construction;
3. To identify industrialized building systems suitable for employment in the Army's military construction program;
4. To suggest locations most amenable to industrialized building;
5. To identify and discuss possible procurement and implementation procedures; and
6. To provide comparisons between conventional and industrialized construction costs and construction durations.

APPROACH

Each principal goal implied numerous subordinate work objectives.

The first goal, "The provision of background information on the history, characteristics, and direction of industrialized building" necessitated:

1. The collection and review of all known pertinent publications, articles, and documents; and
2. The development of a summary narrative of the voluminous literature.

Similarly, the second goal, "the measurement of the present capabilities of the industrialized building industry," required:

1. The identification of all industrialized building system manufacturers in the continental United States;
2. The development of a detailed questionnaire soliciting information on the design, production, and procurement characteristics of each firm's product;
3. The organization, compilation, and summary tabulation of questionnaire responses; and
4. The analysis of market conditions preferred by industrialized builders.

Thirdly, "the identification of feasible industrialized building systems suitable for employment in the Army's Military Construction Program" demanded:

1. The creation of a detailed description of programmed military construction over the next five years;
2. The development of criteria for ascertaining the acceptability of industrialized building systems for military construction projects; and
3. The application of this criteria to each industrialized building system.

The fourth goal, "to suggest locations most amenable to industrialized building" implied

1. The establishment of a criterion defining "amenability" to industrialized construction; and
2. The application of that criterion to all 82 military construction zones to generate a rank-ordering of promising building projects.

Next, "A discussion of possible procurement and implementation procedures" entailed an analysis of

1. Procurement methods currently utilized by industrialized builders and procedures now permitted under Armed Services Procurement Regulations; and
2. Procurement methods facilitating the incorporation of industrialized buildings into the MCA program.

Finally, "comparisons between conventional and industrialized construction costs and construction durations" precipitated

1. The collection of actual industrialized building construction cost data;
2. The collection of historical cost data pertaining to conventional military buildings;
3. The synthesis of statistical formulae from industrialized building cost data to permit comparisons with conventional construction costs; and
4. The determination of relative construction costs and construction times for selected building types.

SCOPE

The study was mainly concerned with building construction planned for fiscal years 1973 through 1977 (FY 73-77) on Class I, U. S. Army installations in the continental United States. Construction planned for this same period by other public and private groups was considered only to the extent that it affected the purpose of the study.

All Army building types, with the exception of family housing, were considered; however, the study concentrated on six frequently occurring, relatively homogenous building types:

1. Enlisted Men's Barracks
2. Bachelor Officer's Quarters
3. Administrative Buildings
4. Covered Storage Facilities (Warehouses)
5. Tank and Automotive Maintenance Facilities and
6. Classroom Type Training Facilities.

Family housing was not included in view of the current work in industrialized housing being carried on by the Department of Housing and Urban Development (HUD).

All forms of industrialized building were considered to be within the purview of the study. Although architect/engineer firms, construction management firms, and subcontractor firms were queried, primary emphasis was placed on supplier/manufacturers.

Although determination of the overall state of the industry was supplemented by numerous sources of information (see selected Bibliography), the conclusions made regarding the compatibility of each firm's product were based wholly on the information provided by each firm through the questionnaire. In nearly all cases, persons answering the questionnaire represented responsible positions in the companies, ranging from the president to the director of marketing. While the accuracy of the data so obtained has not as of yet been subjected to independent verification, confirming evidence of the veracity of manufacturer-supplier survey data exists in the form of various Naval Civil Engineering Laboratory studies and the large percentage of firms disqualified from consideration on the basis of their questionnaire responses.

TERMINOLOGY

Owing to the difficulty of providing precise meanings for certain industrialized building concepts, semantic distinctions peculiar to the Corps of Engineers, and the numerous connotations of construction terminology in everyday usage, the information presented in this study is highly susceptible to misinterpretation.

To minimize subsequent confusion and misunderstanding, the following glossary of terms is provided:

BUILDING: 1. the planning, designing and constructing of structures to house specified activities; 2. a structure so planned, designed and constructed.

Determining building requirements, designing the building and preparing plans, specifications and procurement documents are not generally thought of as being a part of the process called building. Instead, they are thought of as activities which precede building. From the viewpoint of an owner or client, however, the building process begins with these activities. It is from the owner/user's viewpoint that building is considered in this study, hence the expansion, for many, of the term "building" to include these activities (indicated by the words "planning" and "designing" in the glossary definition).

BUILDING PROJECT: any collection of the building types planned for construction during fiscal years 1973 through 1977.

A building project is currently understood to be a collection of one or more buildings, along with the necessary support facilities (i.e., paving, utility lines, etc.), specified as a line-item in the military budget and designated for construction in a particular fiscal year. The Army prepares a plan of its needed building projects for five years ahead. Since the feasibility of industrialized building for a particular building type is a function of the number of buildings involved and their locations, it was necessary to aggregate buildings of the same type into different groupings defined, for the purpose of this study, as "projects."

BUILDING PERFORMANCE: A measure of the aggregate benefits derived from the operation and utilization of a building.

The concept of building performance includes three related but distinct areas of concern: functional performance; product performance; and cost performance.

In this study the functional performance of buildings is defined as the user's satisfaction with the physical environment, the spatial environment and the flexibility of the building.

Product performance, in turn, shall refer to the satisfaction of standard performance measures of the physical components in a building: its structural shell, services and contents (e.g., lumens of light, acoustic repressions, etc.).

Finally, cost performance shall pertain to the satisfaction of criteria for cost control in building operation, maintenance, and repair (Where operation costs are defined as the cost of energy consumed by energy-conversion systems. For example, expenditures of fuel oil, coal or electrical power are operation costs.).

It follows from these definitions that the evaluation of overall "Building Performance" entails three separate measurements of the deviation of functional, product and cost performance from normative functional, product and cost standards.

BUILDING SYSTEM: A scheme for building which is distinguished by certain characteristics of the process and of the product remaining essentially unchanged for each new building constructed.

BUILDING TYPE: a category of buildings constructed to house a specific activity(ies).

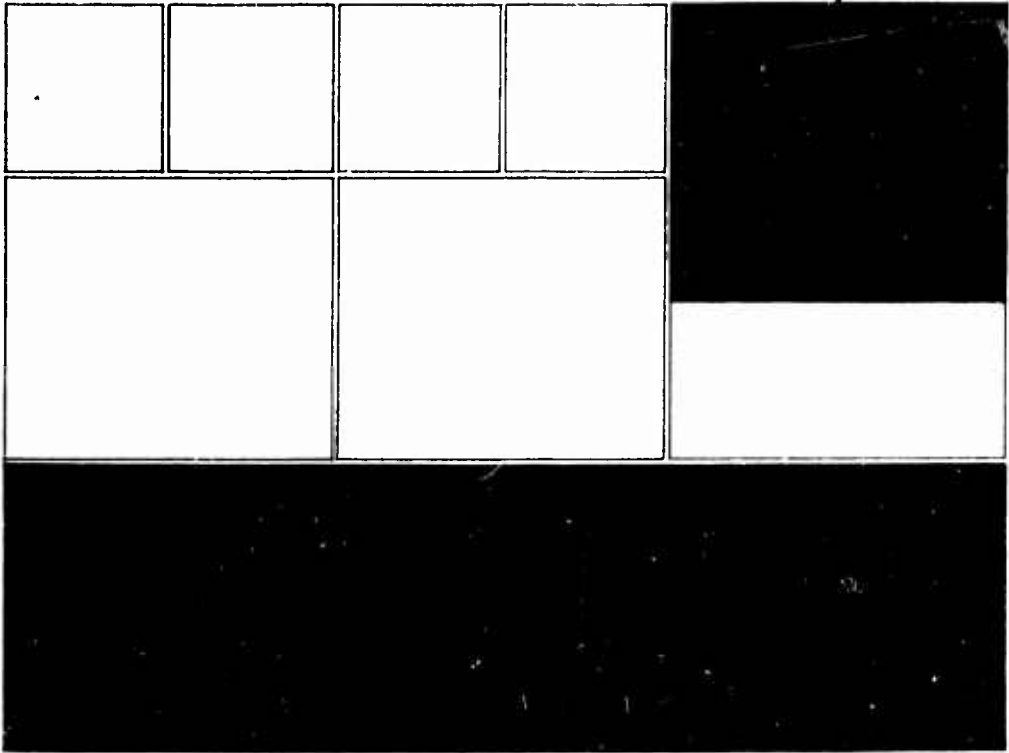
INDUSTRIALIZED BUILDING: 1. building accomplished primarily in the manner of an industrialized process; 2. a structure built in this way.

Admittedly, the meaning of this term varies with each person's interpretation of "primarily" and of "in the manner of an industrialized process." Since virtually all building in the United States is to some extent industrialized, the possible variation in interpretation is quite large. No doubt this accounts for the fact that "industrialized building" is redefined in nearly every study or article in which it appears. Nevertheless, the above definition should provide a level of meaning, though imprecise, sufficient to understand the content in those portions of the text in which the term appears. Further insight into the nature of industrialized building is provided in Chapter 2.

INDUSTRIALIZED BUILDING SYSTEM: the services and products required in a building system utilizing industrialized building.

SYSTEMS APPROACH: A strategy for applying systems building which considers building to be divisible into a set of interrelated elements that can be individually shaped and then connected together to provide the best building system, within existing constraints, for a given purpose.

These definitions shall be adhered to throughout the succeeding narrative.



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CHAPTER 2 – BACKGROUND

CONDITIONS FOR INDUSTRIALIZATION

Current Conditions

Modern history has seen great technological advances taking place during periods of national crisis. Times of stress and unusual need have mothered many inventions, causing men to break tradition to seek methods of accomplishing desired ends in less time, at lower cost or in a superior way. This is particularly true in building. Following the two major international wars in our century, for example, the dire need for construction engendered and fostered the modern movement in architecture, paralleled by unprecedented development of new materials and methods of fabrication and erection.

Today's counterpart to those periods of history is seen in the critical needs of the urban society where building activities must increase many-fold to meet the demands for community facilities. This urban crisis has a variety of causes, all of which cannot be simply identified, however, certain problems do immediately reveal themselves:

1. In both North America and Europe, there is an immediate and increasing need for buildings to house man's activities.
2. Construction costs have risen beyond the reach of many potential customers.
3. Building codes impose contradictory and overlapping standards throughout the country.
4. Governmental financial support of construction has decreased as tax-based sources resist.
5. Shortages of labor in specific trades are becoming more frequent.

It is this climate of great necessity that has spawned a recasting of roles for designers, clients, fabricators and builders, along with a reordering of building processes, to bring into being today's industrialized building.

Historical Conditions

Emphasis is made on today's industrialized building, as the basic concepts used in industrialized building are not new and have been used for centuries. For example, componentized housing, field erection of shop-produced parts, the transporting of prefabricated buildings to distant sites, and the development of industrial capacity to manufacture great numbers of similar units all have early prototypes.

The demountable tabernacle of the Jews is probably without equal as an ancient precursor to prefabricated construction. Some thirty-three centuries have passed since Moses received specifications from Jehova directing the assembly of the wood, bronze, silver, gold, linen and leather components of the portable sanctuary. Though Phoenician, Egyptian and Roman tent-shrines are known from antiquity, this 75' x 150' x 20' high structure was so devised that when camp was broken, all its sacred pieces could be transported by hand and in six covered wagons. It was reassembled on innumerable sites during the forty years of Sinaitic wanderings.

In the early 17th century a panelized wood house was introduced to Massachusetts by the English for use by a fishing fleet. Initially located in Cape Ann, it was disassembled and re-located many times.

One of the earliest componentized houses was developed in Moscow, and was well underway by 1636.

One on-the-scene observer, Archdeacon Coxe, described the process: "The purchaser . . . mentions the number of rooms he requires, examines the different timbers, which are regularly numbered, and bargains for what suit his purpose. The house is sometimes paid for on the spot, and removed by the purchaser; or the vendor contracts to transport and erect it upon the place where it is designed to stand. It may seem incredible that a building may be thus bought, removed, raised and inhabited, within the space of a week."²

¹Tabernacle, Pictorial Bible Dictionary; Zondervan, Grand Rapids, 1967, pp. 821-823.

²George Hamilton. The Art and Architecture of Russia, Harmondsworth (Engl.), 1954, p. 107.

Two notable 19th century structures had large portions of their components shop-fabricated. In London in 1850, the iron-and-glass Crystal Palace of Joseph Paxton solved many problems in assembling precast and tooled parts into a complex building. The erection of this

immense greenhouse-like structure proved the validity of industrialization as an answer for fast, economical space, as it was erected in four months.³ In Paris, the 984' cast iron tower for the exposition of 1889, designed and built by bridge-builder Gustave Eiffel developed many building techniques utilized today. Componentized stairs, greenhouse guttering, curtain walls and exposed iron structure all have in their ancestry these two structures, designed and built in record time.



These historic predecessors show manufacturing from the periods of the Renaissance and the Industrial Revolution which embodied principles of modular dimensioning, mass production, and prefabrication, all basic concepts of industrialized building which were later developed to higher degrees. Beyond the maturation of the basic concepts, the changes that have occurred have been with:

1. the sources of energy used for manufacture
2. the materials
3. the machinery
4. the mode of application and assembly

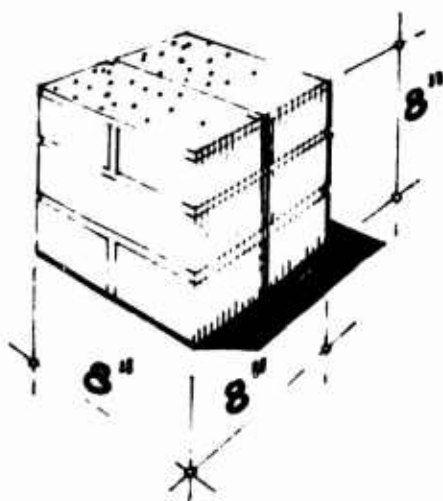
THE NATURE OF INDUSTRIALIZED BUILDING

Manufacturing Concepts Basic to Industrialized Building

Modular dimensioning: The adoption of a standard module of 10 cm in Europe and 4" in non-metric countries plus larger grids based on multiples of those bases, has been another positive contribution to the development of industrialized building. Obvious as it now seems, the adoption of governing principles for joints, graphic conventions and building-within-a-module required international conferences and a slow evolution of thinking in the industry.⁴

Mass production: The following requisites for mass-production may promote efficiency and economy when applied to housing as well as to industry in general.⁵

1. Standardized components. Since "carbon copy" housing has met with buyer resistance, and retooling and customizing is costly, a reasonable alternative is standardized, but interchangeable parts of houses.

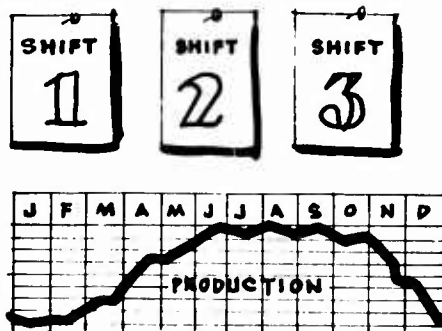


³Christopher Hobhouse, 1851 and the Crystal Palace, London, 1950.

⁴Three sources review the reasoning and usefulness of a grid: Bemis, Rational Design, 1937, Modular Coordination in Building, European Productivity Agency of the Organization for European Economic Cooperation, 1956, and Darlington (ed.), Modular Practice, Modular Building Standards Association, 1962.

⁵These requisites form a part of the 1960 Encyclopedia Britannica article on Mass Production, with comments added which relate specifically to industrialized building. A similar list is given by Lewicki, Building with Large Prefabricates, 9.

2. Long production runs. Producers of industrialized housing have given estimates for the number of units required for investment amortization varying from 500 to 5000, but there is no disagreement that the investment-to-income relationship is bettered with continued output.
3. Continuous plant operation. Round-the-clock work and the elimination of seasonality—a serious construction problem—can maximize a plant's available time, space and machinery to provide a return on its large initial cost. Increased production, though requiring additional manpower, has often decreased unit costs.
4. The use of specialized handling equipment. Palletizing, fork lifts and cranes for large component handling have increased output, as has the adoption of industrial fasteners such as button-punching, stapling, automated nailing and contact cementing for shop and field assembly.
5. Optimized operations sequences. In some systems building, optimization has eliminated some trades, such as plasterers and painters. It has also brought into being multifunctional products, such as wall units that are not only a visual, thermal, acoustical and security screen, but which contain integrated mechanical and electrical components for plug-in installation during the erection.
6. Simplified, repeated work procedures. The maximum specialization of labor is a logical extension of a process that has been taking place since early man began to develop trades in primitive settlements. This isolation of operating steps has also laid groundwork for automation, the performance of work by machines without human intervention or direction.
7. Systematic planning, direction and control. In design and construction, scheduling often aims to involve the planner, fabricator and erector simultaneously, and has been given acronyms such as PERT and CPM.⁶



Prefabrication: Building components, factory-fabricated and transported to the site for permanent installation, are the products of industrialized building. The size, number and complexity of those components has continued to increase, beginning with the common brick and progressing to the "20th Century brick" (Paul Rudolph's name for the prefabricated residential module). The use of compatible parts, panels and components has generally been more financially feasible, however, than has the prefabrication of whole living modules, a process sometimes called "building with a box."⁷

Processes: New Ways and Means

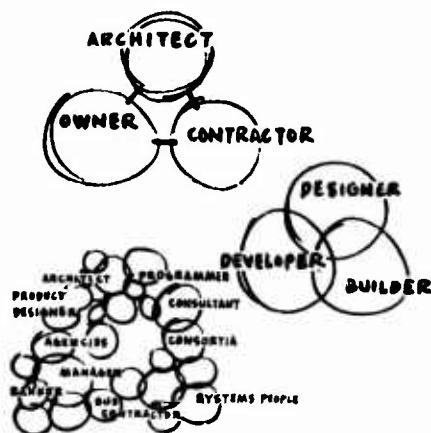
Because traditional means have failed to provide the needed buildings, the relationships of people in the building trades have changed and are changing radically. Collectively, the effort represents a vast redeployment of resources—of methods and materials as well as men—but some of the most significant changes have to do with management and with the roles that various participants play in building within the systems concepts.

⁶PERT (Program Evaluation and Review Technique) and CPM (Critical Path Method) are scheduling devices which graphically chart a project's development in a linear form, usually showing concurrent operations. See David Stires and Maurice Murphy, PERT-CPM.

⁷Battelle Memorial Institute, The State of the Art of Prefabrication in the Construction Industry, Columbus, Ohio, 1967, pp. 20ff, 138.

Management functions: Industrialized building is far more than "package building." The organization of clients, financiers, manufacturers, government, consultants, designers, and labor into a cooperating team to provide input from the beginning is an important development of the 1960's. (The term "consortium" has been popularized to apply to such clustering of contributors.) Many projects, not having the advantage of such combined resources, have floundered in conception.⁸

The American Institute of Architects now recognizes the necessity of teamwork from concept to completion, which is a revision of the architect's former professional stance as a "disinterested" mediator between builder and owner. In fact, national AIA President Robert Hastings noted that the collaborative approach has much potential for cost-cutting, providing, through earlier occupancy, an additional monetary advantage to the owner.⁹



Changing roles: The architect/owner/builder relationship, formerly a well-defined triad, is increasingly experiencing overlapping and diffusion, and in some cases obliteration.¹⁰ More than ever before, responsibilities are being shared in programming, design, fabrication and project management.

A pioneering German architect advanced artist-technician teamwork and project scheduling. Walter Gropius' Fagus Factory (1911) and Werkbund Building (1914) contained ideas for industrialized products which helped to make machine age designs palatable to consumers at large.¹¹

Gropius' post-World War I school of design, the Bauhaus, proposed to integrate art and technology, and this aim was realized in the school's own buildings, which featured curtain-wall construction and prefabricated furniture. The Bauhaus' faculty integrated industrial materials and operations into architecture and furnishings, responding in a critical time to shortages of men, material and capital, to provide solutions to an acute problem of insufficient construction.¹² Tubular steel furniture, plastics as a structural material, and the development of new trades and craftsmen owe their beginnings to this school, born of necessity in a time of need.

Gropius went much further to promote industrialized building with three precursory prefabricated housing projects. At Toerten (1826-29), he furthered the on-site coordination process; at Weissenhof (1927), he developed dry-wall construction; in his 1931 prefabricated copper houses, the concept of interchangeable parts and many joint problems were solved; in all three, he carried further the standardization of components.¹³



⁸Burnham Kelly, *The Prefabrication of Houses*, New York, 1951, pp. 71ff.

⁹Speech during Architecture and the College Conference at the University of Illinois on April 19, 1971. The validity of such practice is set forth in detail in McCue and Ewald, *Creating the Human Environment*, Urbana, 1970, pp. 157ff, 239ff.

¹⁰The federal government, recognizing a growing trend, required architect-contractor collaboration in Operation Turnkey.

¹¹S. Giedion, *Space, Time and Architecture*, Cambridge, Mass., 1954.

¹²Walter Gropius, *The New Architecture and the Bauhaus*, Boston, n.d., pp. 51-67.

¹³S. Giedion, *Walter Gropius, Work and Teamwork*, New York, 1954, p. 75.

FORMS AND PHYSICAL COMPONENTS

The Products with Which to Build

As the shop fabrication of "building blocks" has evolved from a hand-sized brick to larger and more complex units, the site assembly has also enlarged, requiring specialized teams and machinery. Significant prefabricated types may be called components, sub-systems or even systems, and may be categorized as:

BOXES, usually with load-bearing walls: A factory-finished (or substantially completed) living unit (or partial living unit), requiring little more than positioning, anchorage and connections to utility mains at the site. "Building with the box" may permit stacking of such units, requiring stronger walls.

PROBLEMS: Leveling, anchorage, utility connections, uneconomic volume to transport.

ADVANTAGES: Complete factory fabrication is possible

EXAMPLES: HABITAT, WATES, PALACIO DEL RIO, STERLING-HOMEX, and OLIN HEALTH CENTER (Lansing, Mich.), each quite unique.

The "box," whose early origins included field hospitals and gypsy wagons (ancestors of today's mobile homes), has evolved into prefabricated apartments which hold promise, ultimately, for use as "plug-in" modules for highrise housing construction.

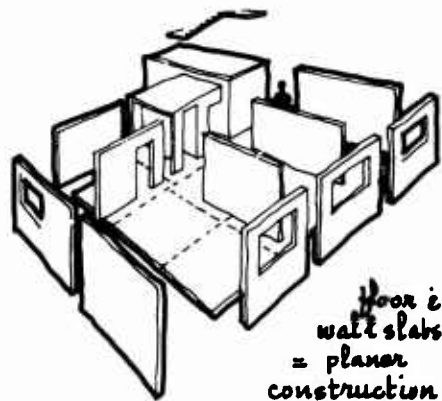
PLANAR (floor and wall slabs): The enclosure of space with structural planes to provide a shell for site finishing. A preponderance of European work has been of this nature, utilizing precast concrete, some with integral insulation. Lighter weight slabs—either wooden balloon-frame or composite "sandwich"—have been used, primarily in the U. S.

PROBLEMS: Connections, weatherproof joints, heavy weight, and short spans.

ADVANTAGES: Almost by definition, such slabs could comprise an open system. More compact for shipment than a "box." Some simple units are site-fabricated.

EXAMPLES: BALCO, BALENCY, BISON, OMNIFORM, FOLDCRETE

Some planes have been hinged for shipment, then folded out for erection, but these have met with limited success.



floor &
wall slabs
= planar
construction

SKELETAL FRAMES (Steel and pre-stressed concrete): A structure supporting and anchoring all other building elements. Some structural components form floors, ceilings, roofs and walls.

PROBLEMS: The achievement of precision and quality finish on concrete castings.

ADVANTAGES: With controlled factory conditions, most mass-production advantages are realized. Lighter than precast, loadbearing concrete slab construction.

EXAMPLES: COMPONOFORM, DUOTEK, TOWNLAND, TRIPOSITE, BUTLER, and standard prestressed concrete units. SCSD roofs.

Trusses, including open-web joists, spaceframes and, when warped, geodesic domes, have also been hinged to steel decking for a foldout application in subsystem for schools.

CONCRETE POST-TENSIONED ASSEMBLIES: Heavy precast components with conduits for receiving tendons for tightening.

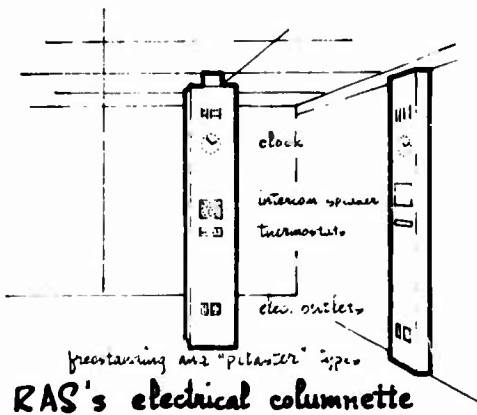
- PROBLEMS:** Limited knowledge of post-tensioning technology; special machinery required on site.
- ADVANTAGES:** A lighter, integral structure.
- EXAMPLES:** Stone's Commonwealth of Kentucky Office Building, Gulf Life Tower

CONCRETE LIFT-SLAB, TILT-UP, SLIP-FORM, SHEAR WALL: All resulting in planar construction, these methods require cranes on site, and most have peculiar connecting details.

- PROBLEMS:** Possible movement with temperature change, attachments of other systems.
- ADVANTAGES:** Other trades' work may be decreased.
- EXAMPLES:** Knights of Columbus Building, Balenry MBM.

INFILLING COMPONENTS: Non-structural planes, designed and fabricated to provide a building envelope, and attaching to the building's structural frame.

- PROBLEMS:** Condensation, moisture seals, the "mechanized" appearance.
 - ADVANTAGES:** Thin, lightweight, speedily installed in any weather, with no scaffolding, thermally superior to concrete.
 - EXAMPLES:** RELBEC, SYSTEM III, AMERICAN WOOD SYSTEMS, FEAL.
- Sheet materials of composite construction (plywood, gypsum board and insulated sandwich panels), and metal framed fenestration developed for more conventional construction adapt well to industrialized needs.



MECHANICAL SYSTEMS (open): The complex of heating, cooling, humidifying, dehumidifying, moving and cleansing of air; of electric and electronic sound, lighting, visual, power and control systems, permitting rearrangements to service a dynamic and changing set of interior spaces.

- PROBLEMS:** Servicing roof top HVAC units (which were designed for mild climates) is difficult.
- ADVANTAGES:** New flexible ductwork adapts to changing interior spaces.
- EXAMPLES:** Lennox, SEF's "control column."

MECHANICAL CORES: The grouping of fixtures and fittings (usually plumbing and HVAC), factory-assembled to the degree that only connections to supply and waste are required in the field. In housing, back-to-back arrangements for kitchen-bath assemblies are a logical cluster, and in some arrangements, the addition of HVAC and laundry components have provided a compact and economic package.

- PROBLEMS:** Leveling, labor union domains
- ADVANTAGES:** Shorter utility runs
- EXAMPLES:** NYC's brownstone rehabilitation "plug-in," B. Fuller's Dymaxion utility core.

PARTITIONING: Vertical planar assemblies to provide a visual screen, an acoustic barrier and security. Additional systems requirements include interfacing with an integrated ceiling (see below), a curtain wall, and the floor, optional facings (chalk- and tack-boards, movie screens, laminated plastic), as well as quick and easy movability.

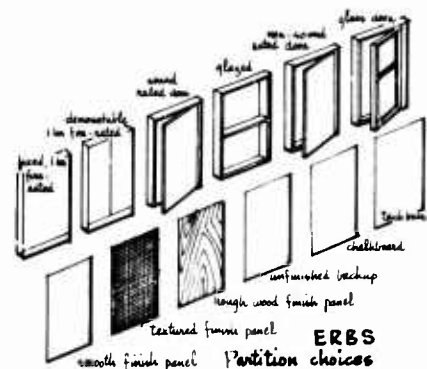
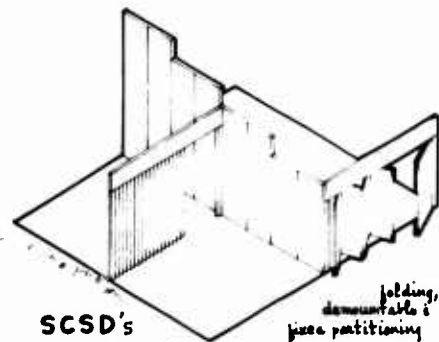
- PROBLEMS:** Electric controls (light switches, power outlets, and thermostats), security, fire ratings.
- ADVANTAGES:** A flexible changing of spaces is permitted.
- EXAMPLES:** Mills, Hauserman.

INTEGRATED CEILINGS: The upper horizontal plane over an interior space which in many constructions now provides a visual barrier, fireproofing for steel construction, acoustical absorbency, the incorporation of lighting fixtures, sprinkler heads, partitioning anchorage (with closures), HVAC supply and return, and speakers for electronic sound.

- PROBLEMS:** Labor domains; the most visible design elements becoming "machined" in appearance.
- ADVANTAGES:** Light weight, relatively easy to change.
- EXAMPLES:** Armstrong, Commonwealth of Kentucky Building (post-tensioned concrete).

FURNITURE: Seating, shelving, display, study carrels, and similar components useful for tailoring an interior space for a particular occupancy.

- PROBLEMS:** Multiplicity of fittings, attachments, panels
- ADVANTAGES:** Convertibility, lightness
- EXAMPLES:** URBS, SEF.



EUROPE: 1945-1970

Europe Rebuilds—In Different Ways

A study of the causal factors, successes and failures of European industrialization in the two postwar decades, provides some guidance for current work.

The accumulated effects of the economic extremes of the 1930's and the destruction of the war, with its enforced migrations and rapacious gobbling of materials, left much of Europe with shortages of buildings of every type. Not only had there been two decades of stunted construction, but the postwar exhaustion prolonged and increased those shortages on into the 1950's. The lack of labor and materials called for extraordinary means to rebuild faster than conventional construction would permit. Changed circumstances demanded different "satisfiers."

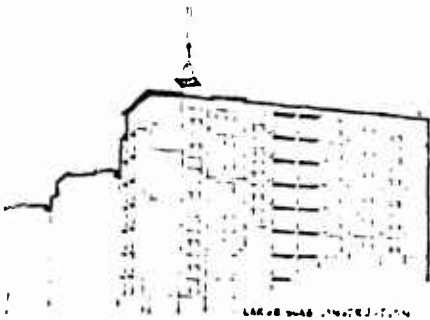
The most obvious needs were for schools and for housing. Both building types seemed to be especially amenable to prefabrication, and lent themselves, because of room sizes, quite well to the use of concrete.

Extensive activity in industrialized building in Europe was the result of several factors: 1) government subsidies were provided in much of Europe, 2) Denmark established a national law requiring building regulations to include provisions for modular coordination, 3) the United Kingdom, although purported to be accomplishing the changes through close cooperation between the government and industry without imposing a law, through

the Ministry of Housing and Local Government, required that by the end of 1971, all housing schemes submitted for loan sanction approval have to take account of metric British Standards for new products and components, 4) the U. S. S. R. with a centrally planned economy and a social housing policy appeared to be fully committed to industrialized building in the urban area, 5) France embarked on a long term industrialized housing program, again, with government support comprising about 60% of residential construction, and 6) Sweden, also primarily financing from the public sector, encouraged industrialization to the extent of allocating a fixed quota for its accomplishment.

As several European systems seek licensees in the U. S., the standardization and policies by which they have developed will be reflected in those systems. Due to the wide availability of building systems throughout Europe, several international organizations have been established to facilitate this inter-country marketing and promote the further use of industrialized methods. Several of these are: The International Organization for Standardization,

British Standards Institute, Permanent Committee on Building of the Council for Mutual Economic Aid, and Committee on Housing, Building and Planning of the U. N. Economic Commission for Europe. There are numerous other conferences and committees of the U. N. such as Dimensional Co-ordination in Building: Current Trends in ECE Countries (Geneva, 1966).



Current European Enterprises: East and West

U. S. S. R.: Russian Statistics indicate that their nationalized industrialized housing program is the world's largest.¹⁹ Recent Russian claims are that man-days/sq. meter of floor space have been reduced from 2.5 (for conventional construction) to 1.5 (with industrialization), counting both plant and site labor.²⁰ A primary problem has been unattainable goals set by management (government). About 24 million apartments were built

from 1959-1969,²¹ about 80% of which were almost completely prefabricated.²² Prefabricated concrete rooms are considered too cumbersome to warrant continued development, so panel construction is favored, but even so, most are closed systems.

MAJOR SYSTEMS: Massive Box, Lightweight, Waffle slab, Large Panel.²³

POLAND: Poland's industry, also nationalized, is considered by HUD to be Europe's most advanced.²⁴ A Warsaw expert called large precast concrete units the "basis of the industrialized building industry," and noted an interesting forerunner of box construction in "ready-made sanitary cubicles" (toilets), which, when stacked, formed a structurally independent tower within an otherwise traditional building.²⁵ Most of their housing, however, is panelized, and largely of closed systems.

MAJOR SYSTEMS: Kask I and II

¹⁸R. E. Platts, *System Production of Housing in Northern Europe*, Ottawa, 1969, and R. M. E. Diamant, *Industrialized Building (I and II)*, are prime sources for statistics and coverage of systems.

¹⁹*Industrialized Building (HUD)*, op. cit.

²⁰A. Vilar, (Editorial), *Building Construction*, Oct. 1969, p. 7.

²¹J. Winkler, *Architectural Record*, Oct. 1969, p. 169.

²²Walter Meyer-Bohe, speaking at the Swiss Manufacturers Concrete Prefabricated Elements Conference, Berne, 19 March 1968.

²³These are component types (rather than trade names), since Russian building is nationalized; comparisons, therefore, cannot be made with free market/private enterprise programs.

²⁴*Industrialized Building (HUD)*, op. cit.

²⁵Lewicki, op. cit., p. 9, 54.

CZECHOSLOVAKIA: Heavy precast systems combine loadbearing walls with skeletal structures, some with "beamless skeleton" (capped columns and a two-way slab), and some which utilize precast spread footings and grade beams. The complexity of problems are due to dimensional coordination and standardization (including tolerances), proliferation of components, and intricate castings.²⁶ Long range production planning, requiring 10-20 years, concentrates on a single closed system model, relating all development and automation to it.²⁷

MAJOR SYSTEM: Vum (Nationalized)

UNITED KINGDOM: Around 440 private systems endeavors emerged in less than a decade, though less than a dozen remained solvent beyond withdrawal of government subsidies. Cost saving factors are due primarily to speed of construction, and include the contractor's shortened overhead time, the client's earlier occupancy, a decrease of construction insurance and interest, and an earlier scheduling of road and sewer construction.²⁸ The programs have had a wide variety of building types (though a majority have been for schools and housing), as well as varying degrees of open-to-closed systems.

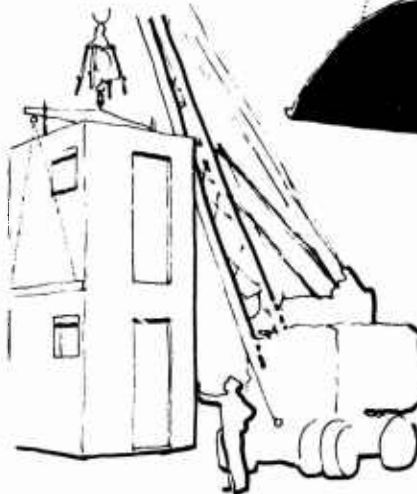
MAJOR SYSTEMS:²⁹ Thamesmead, Wates (OB),³⁰ Bison (OB),³¹ Cebus (OB), Interbuild, Terrapin, 5M SF1, Belfrey, Clader, Nenck, Wil-Mac, Truscon, Cubitts 4-Storey, Bakelite (plastic), Clasp, Terson, Spacemaker, Condor, and most recently Cosmos, claimed to be their first completely open system for housing.³²

SWEDEN: Without subsidies, private enterprise prefabrication has fluctuated, though its adoption as a total process by the housing industry will increase 15% by 1975.³³ One Source says that 60% of the total building volume—including wood systems—is prefabricated.³⁴ Schemes vary, using mechanical cores (a box), slabs and other components for comparatively open system possibilities.

MAJOR SYSTEMS: Heart-Skansa, Skarne, All Concrete, Sundh, Corpus, Hjartat, Erbest, Malmö, Linköping, Sipores-Salemstaden, Elementhus.

DENMARK: As of 1969, some 60% of the 50,000 housing unit/year output was industrialized,³⁵ up from 20% in 1965.³⁶ With Britain and France, the Danes lead in industrialized building in western Europe.³⁷ A large portion of housing is panelized and multistory, and only partly open.

MAJOR SYSTEMS: Larsen and Nielsen, Jespersen (OB) or 12M (also licensed in Britain with John Laing and in the U. S. as Jespersen-Kay), Conbox, Relbec (OB).



A "HEART" UNIT

²⁶ Ibid., pp. 47, 59 and 74.

²⁷ National Monograph of Czechoslovakia, Prague Seminar, Vol. II, pp. 287-297.

²⁸ David Brett (of Condor International, Ltd.), speaking at the Industrialized Building Exposition and Congress, Inc., November 1970, Louisville, Ky.

²⁹ In Interbuild, London, 1965, some fifty manufacturers are listed. Those named here are fairly representative of major operations. See also British Prefabricated School Construction, SCSD Report No. 2, (EFL), New York, 1968 n.d.

³⁰ Concrete Ltd. = Britain's largest (P. Schryver, in Forum, Oct. 1969, pp. 12ff).

³¹ (OB) = firms whose systems were submitted as parts of entries in HUD's Operation Breakthrough. Not all those were selected as finalists, however.

³² Architectural and Engineering News, May 1969, p. 37.

³³ Monograph of Sweden, International Federation of Building and Public Works, The Social Aspects of Prefabrication in the Construction Industry (Paris, 1967), p. 1.

³⁴ Meyer-Bohe, op. cit.

³⁵ A. Vilar, op. cit.

³⁶ Kjeldsen and Simonsen, Industrialized Building in Denmark, Copenhagen, 1965, p. 18.

³⁷ Industrialized Building (HUD), op. cit., p. 8.

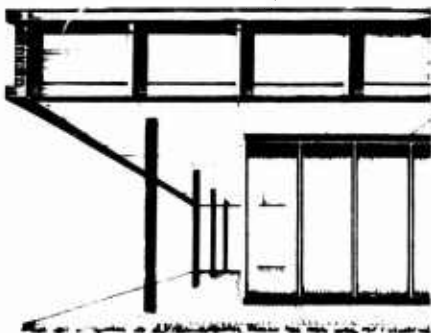
Italy: Private producers have developed considerable "open system" capability, especially using steel framing. The Balency System developed movable concrete precasting plants whose special machinery cost \$200,000, plus up to \$300,000 for batching plants, tower cranes and tractors.³⁸ Designed to produce 500 dwellings/year (using two in-plant shifts and one for assembly), the equipment would, if depreciated over five years, bring costs attributable to that machinery down to \$200/dwelling, or only \$.20 sf.³⁹

MAJOR SYSTEMS: Feal, Balency (Impresa Generale Construzione MBM—licensed in several countries).



INDUSTRIALIZED BUILDING IS NOT
FREEFORM AND INDIVIDUALISTIC...

...BUT IS DISCIPLINED, REGULAR



FRANCE: The private development of a steel-framed system, Project Experimental de la Grande Mare, won the R. S. Reynolds Memorial Award of 1970 for its use in an apartment complex at Rouen.

Its open planning capability permits a personalization, indicating a maturing of industrialized building. This system is being marketed in the U. S. as System III by Component Building Systems, Ltd. Twenty-two percent of total French building is prefabricated.⁴⁰

MAJOR SYSTEMS: Balency (OB), Coignet (OB), Tracoba (OB), Sectra (OB), Costamagna, Fioria.

NETHERLANDS:

MAJOR SYSTEMS: Concrete Building Systems, Schockbeton.

WEST GERMANY: Less affected than most of Europe by large scale industrialized processes—probably because of the high development of industrialization using smaller scale units.⁴¹ Germany's private industry continues construction using precast concrete plank floors, roofs, stairs, and reinforced masonry unit walls for all types of construction. Only 4% of the industry is completely prefabricated, however.⁴²

MAJOR SYSTEMS: Niedersachsen, Balco, Okal Hans.

AMERICA: 1945-1970

The Challenge of Prefabrication

Wartime building, under pressures of time, labor shortages and a need for demountability resulted in quonset huts, tar-paper barracks and stock plans. While these might have been reasonable answers under wartime conditions, they gave prefabrication an image of impersonality and cheapness from which it still suffers.⁴³ However, American industrial production for the war was very impressive. The accomplishments in all areas during the conflict were added to the designs and research of the 1930's to convince many of the potential of industrialized housing.

Indeed, when the depression virtually shut down the building industry, a number of private and public efforts emerged which ranged from fantasy to responsible research. In the latter category, the Pierce Foundations' Housing Research Division was established in 1931, in 1935, the Research Foundation Housing Project at Purdue University began, and in 1938, the Bemis Foundation embarked on what was to become a significant study of prefabrication. Collectively, through research and testing of materials and methods, these foundations built a profound body of knowledge. And the government, through the Forest Products Laboratory, the Bureau of Standards, the Farm Security Administration, and the Tennessee Valley Authority, designed, tested and built up to whole communities, based on the most advanced thinking of the time. The use of new sheet materials and industrial techniques were a part of these programs.

³⁸This is 1/10 the reputed cost of one proposed U. S. Plant which would require 800 dwelling units/year to justify the required investment. Arthur Bohnen, Component Building Systems, Ltd., in a speech at the University of Illinois, 4 May, 1971.

³⁹R. Merzaglia, Engineering News-Record, Oct. 27, 1966.

⁴⁰Meyer-Bohe, op. cit.

⁴¹An example of German capabilities was the development of a West Berlin community in the late 1950's. Called INTERBAU, it involved international teams of architects and builders, and is a model of planning and building coordination.

⁴²Meyer-Bohe, op. cit.

⁴³Battelle, op. cit., p. 17.

By 1950, hundreds of private companies had tried the "prefab" route to quicker, less costly housing, but the majority of them became defunct. In spite of this high mortality rate, the 1948-50 period saw about 15%/year increase in prefabrication volume.⁴⁴ Some of the more notable of the industrialized houses were an updated DY-MAXION HOUSE of Buckminster Fuller,⁴⁵ NATIONAL HOMES,⁴⁶ LUSTRON,⁴⁷ and GUNNISON HOMES,⁴⁸ a subsidiary of U. S. Steel. Most of these had fixed plans, with few "customizing" possibilities.

In the next dozen years four more were to appear which had been carefully researched and designed, but which generally were unable to muster the volume necessary for amortization.

The FERRO HOUSE—a new model from an old line manufacturer (from 1932)—featured steel framing and steel-faced "sandwich" wall and roof panels providing low maintenance. Some 20 accessory and component firms collaborated on this project.⁴⁹

KOPPER'S DY-LITE, utilizing General Homes' experience (Koppers bought half-interest in their company in 1962), developed plywood sandwich panels for cladding which were site-erected by crane in half the time required by other "pre-fabbers," and one-fourth that for conventional construction.⁵⁰

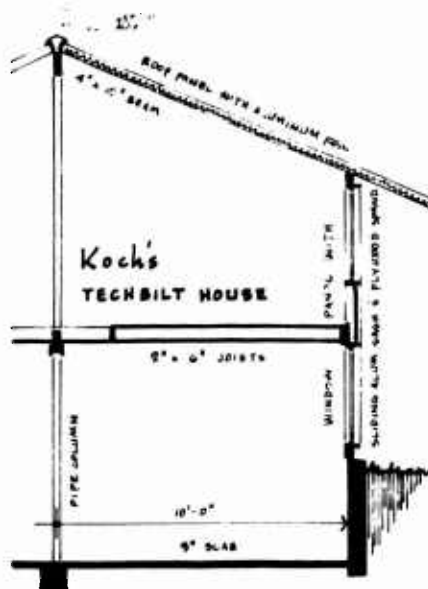
TECHBILT, by architect Carl Koch, an exposed wood-framed panelized house, began sales in 1953 at \$15,000. An enlarged plan and inflation increased costs to \$42,000 by 1965. Its shipping radius was limited to 250 miles, and construction required six weeks.⁵¹

ALSIDE, an exposed steel, open-system Miesian* house promised an unprecedented choice of 22 plans, and many accessories and amenities such as double-glazed sliding doors, air conditioning and aluminum-faced wall panels, the latter produced by automated presses. Construction time varied from two to four weeks, the "radius of economy" was 600 miles, and costs were supposed to run from \$18,000 to \$40,000 (including land). After selling 200 homes and suffering an \$8 million loss from its inception in 1963, the company returned to producing siding.⁵²

Prefabricated houses which have been successful keep hopes up and encourage new research and development, as well as new entries into the field. Notable ongoing operations have been made possible through government help in over-coming constrictive codes (a bane of former marketing efforts), through a high rate of automation which cuts fabrication time, new erection techniques and machinery which reduce erection time, and through the use of rail transport to widen the marketing area.

Mass-production requires mass-consumption. As a market phenomenon, it is brought about through social and geographic mobility, urbanization, widening educational opportunity, and reduction of income inequities. The resultant consumer equalization is demonstrated by buyers in Albuquerque being more willing to buy products also marketed in Portland, without a special "tailoring" to their specifications.⁵³

*i.e., in the style of architect Mies van der Rhoe.



⁴⁴Kelly, op. cit., pp. 71, 87-96, 419ff.

⁴⁵Only two were produced: market potential was not assured.

⁴⁶The largest producer in 1950.

⁴⁷A closed-plan steel house, which declared bankruptcy in 1950 after a \$37 million RFC loan (they had needed an estimated \$54 million), and four years of operations, which produced almost 1700 homes.

⁴⁸Now USS Homes.

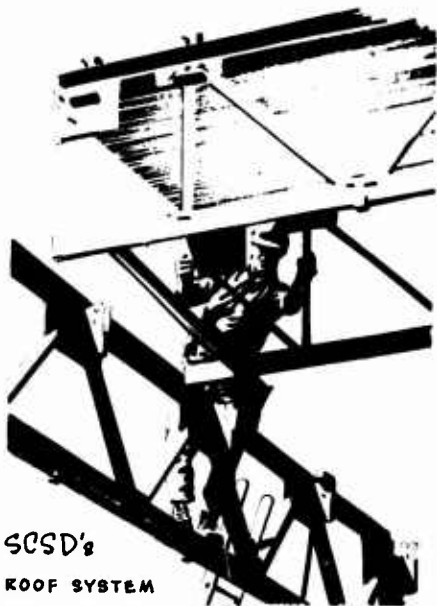
⁴⁹Better Homes and Gardens, Sept, 1969, p. 63.

⁵⁰(The developer's claims)—House and Home, November 1963, p. 95.

⁵¹Ibid., August 1963, p. 83.

⁵²Ibid., November 1963, p. 99.

⁵³"Mass Production," op. cit.



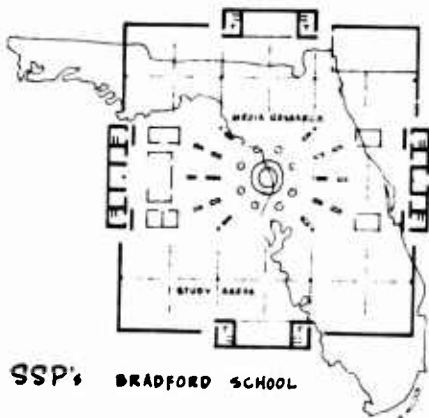
SCSD's
ROOF SYSTEM

The Systems of the Sixties

Early in the 1960's the processes and products of industrialized building underwent a comprehensive reanalysis, which resulted in a new strategy. Teams from the design professions, the construction industry, from education and finance, as well as from various product manufacturers, were brought together for a series of studies. Under the general direction of architect Ezra Ehrenkrantz, the activities were eventually to result in the construction of buildings for thirteen school districts under the School Construction Systems Development (SCSD).⁵⁴

Under initial sponsorship of the Educational Facilities Laboratories,⁵⁵ SCSD developed the "consortium" strategy, which required cooperative involvement from all parties throughout the course of the project, rather than the traditional sequential "taking of turns." The enthusiasm of the interdisciplinary mix of consortia generated a basic set of counter-supportive physical systems for construction—structural, heating/ventilating/cooling, lighting/ceiling, and interior partitions—all of which were covered by performance specifications.⁵⁶ The required "interfacing" of these product systems—they had to fit and work together dimensionally and functionally to provide an open system—spawned a whole set of non-physical systems, rearranging roles and relationships of the participants themselves.

National interest in the program is demonstrated by the fact that two school plants (one in Nevada and one in Illinois)⁵⁷ were bid using the "systems" approach, as well as the components developed in California, even before the original SCSD schools were completed, the interest went beyond economics (though cost was a criterion), but the possibility for conversion of spaces to accommodate a dynamic academic program was a timely answer to emerging educational practices. The concluding consensus was that the buildings were not cheaper, but that the whole product was "more school for the money" than could be had with conventional building.⁵⁸



SSP's BRADFORD SCHOOL

Based on early "success" indicators for SCSD, an extensive program was initiated by the Florida State Department of Education which was called Schoolhouse System Project (SSP). In three initial programs, 24 schools were developed and bid, with costs ranging from \$12-\$17/sf. A tabulation of Program No. 3 costs revealed that if subsystems accounted for an increasing portion of the total buildings, overall costs decreased accordingly. During the time span of the three first projects—from November 1967 through June 1969—general construction costs increased 19% in Florida, but SSP costs were reduced 10%.⁵⁹ The program is proceeding with bulk purchasing, aggregating of projects, and continued research.

⁵⁴The best single reference on this California program is SCSD: The Project and the Schools, New York, 1967.

⁵⁵EFL, a subsidiary of the Ford Foundation, was eventually to underwrite additional parts of the SCSD program, as well as other "second generation" systems.

⁵⁶The specifications document, issued in July 1963, is in itself something of a milestone.

⁵⁷The Bertha Ronzoni School for Las Vegas, and the Barrington, Illinois, Middle School.

⁵⁸The initial budget set at \$25 million was to provide 1.4 million square feet of space.

⁵⁹"Florida's Systems Schools," CEFJ Journal, Jan-Feb. 1970, pp. 14, 15.

Others finding California's comprehensive approach promising were two Canadian groups who organized under the names Study of Educational Facilities (SEF) and Recherches en Ameragements Scolaires (RAS) or Research in School Facilities, of the Montreal Catholic School Commission.

SEF, undertaken by the Metropolitan Toronto School Board in 1965, developed Educational Specifications and User Requirements: Elementary (K-6) Schools, the first of a series of unique reports.⁶⁰ Originally scheduled for use in 32 school buildings, the aim was to devise a completely open system. With the use of computers, some 13,000 components were identified as meeting specifications of the ten major subsystem types, with as many as five interfaces required for some subsystems. A dual contract procedure permitted selection of the subsystems, followed by a tailoring of the winning subsystems to individual school projects. Bid in the spring of 1969, the first 12 schools built cost \$20 million, an escalation of some 53% over estimates scheduled five years before.⁶¹

RAS went farther than SCSD and SSP in that it invited manufacturers to form industrial joint ventures to submit single bids for the package of five subsystems (for which performance specifications were developed) as well as for the rest of the work needed to complete the entire project. Initiated in early 1969, the program aimed to reduce post-bid delays, and received some of the best-developed structural, mechanical and electrical proposals yet to be produced. With 20 private schools (and a possibility for 75 additional ones over the next decade), the beginning program is costing \$37 million. The first group of schools were scheduled to be completed in 1972.⁶²

GREAT HIGH SCHOOLS (GHS) of Pittsburg was begun in 1964-65 as an ambitious \$250 million program to include five school plants of about a million square feet each. An integral part of the city's long range renewal, the program commissioned academic studies and professional services from Harvard to St. Louis, and solicited federal, state and municipal funding. The program, one of the most ambitious ever, sought to go far beyond previous systems projects by including electronic teaching aids and food service facilities, as well as groupings of social/academic units into "houses" for 1250-1400 students. However, school officials canceled GHS in 1970 because of financial and other compounding difficulties.⁶³

Others that have come into being are the GEORGIA SCHOOLHOUSE SYSTEMS COUNCIL (GSSC) and BOSTON STANDARDIZED COMPONENTS (BOSTCO).⁶⁴ By mid-1970, 33 states had completed or had under construction 164 systems schools, with an additional 51 in design or development.⁶⁵

A tabulation of statistics of school systems projects with rounded figures follows.

SCHOOL SYSTEMS TABULATION

| Project | Form | Size in Sq. Ft. | Owner and Facility Type | Scheduled Costs |
|---------|-----------------------------------------------------------------------------|-------------------|---------------------------------------------------|-------------------------------------------|
| SCSD | 4 subsystems ⁶⁶ | 1.4 million | 13 public school districts | \$30 million, continuing. |
| SSP | 6 subsystems | 2.2 million | 24 public schools in 3 initial programs, now more | \$30.5 million, 7 million now underway. |
| SEF | 10 open subsystems | 1.3 million | 23 public schools (reduced from 32) | \$20 million |
| RAS | 5 subsystems | | 20 private schools with possible use in many more | \$37 million |
| GHS | 2 "borrowed" systems, 2 new, with special studies for services & scheduling | 5 million (est'd) | public school board | Programmed for \$250 million, now defunct |

⁶⁰Publication numbers E.1-E.4 are educational specifications, T.1-T.7 are systems study documents (including performance specifications), while A.1-A.2 cover financing and development.

⁶¹"Building Systems Get Firm Grip on Construction," Engineering News Record, Oct. 22, 1970, p.44.

⁶²Newsletter, Building Systems Information Clearinghouse, (BSIC) I-1, Spring 1969, p. 8-14.

⁶³Ibid., p. 18-21; also "Building . . ." ENR, op. cit., p. 44.

⁶⁴Building . . ." op. cit., p. 44.

⁶⁵Listing of Schools Constructed with a Building System, BSIC Special Report Number Two, July 22, 1970

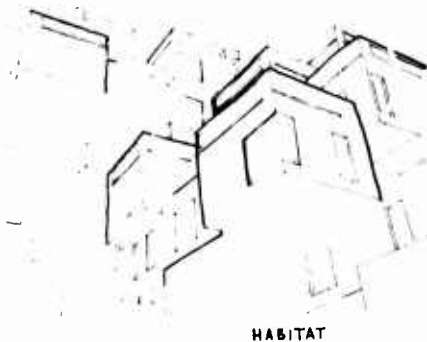
The conditions bringing widespread use of concrete components in Europe are not paralleled on this continent, but a number of structural systems—some integrating mechanical and electrical into them—appeared in the 1960's to show the wide range of possibilities.

University Residential Building System (URBS), initiated by the University of California in 1965 and contracting with Building Systems Development (BSD)—headed by Ezra Ehrenkrantz (who headed SCSD), developed a five-step methodology for a relatively open system:

1. Feasibility study
2. User requirement analysis
3. Performance specifications
4. Receiving bids
5. Component testing⁶⁷

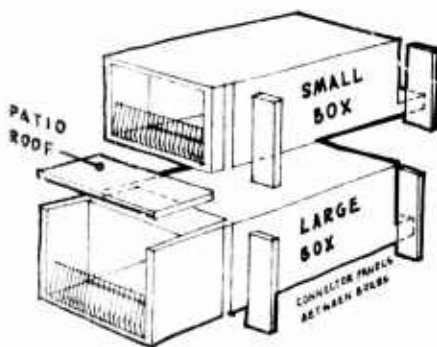
Subsystems included structure/ceiling, bathrooms, HVAC, partitioning, and furnishings. The structure/ceiling winning bid was the first North American concrete system; called Triposite, it consists of precast columns and inverted precast double-tee beams, with a cast-in-place topping and perimeter beams, providing an "interstitial" mechanical space. Programmed and bid for 4500 student units, URBS was reduced, but now has its first project under construction on the San Diego campus of the University of California. The project includes 320 units in two- to six-story buildings and is costing \$29.16 per square foot. Seven hundred more units are in the final design stage.

HABITAT, a government-financed, \$13.5 million experimental housing community built for Montreal's Expo 67,



consists of 90-ton loadbearing concrete boxes. These basic modules were stacked in stairstep fashion to provide 158 living units with one to four bedrooms, with outdoor living terraces and a variety of apartments. It is a closed system with several available models. Access is via elevators and enclosed bridges which separate pedestrian and vehicular traffic. Largely fabricated off-site and lifted into position with cranes, the modules provided a large scale testing of many conceptual schemes, but the overall project size was cut too small to approach economic feasibility.⁶⁸

Palacio del Rio
COMPONENTS



PALACIO DEL RIO, a 17-story hotel for San Antonio's 1968 Hemisfair, was built in 9 months. The "closed system" consists largely of two types of precast vertically-stacked rooms, shimmed with special levelers and knit together with cast-in-place concrete around protruding reinforcing bars. Built in record time, the \$8.5 million hotel's rooms were prefabricated, complete with carpeting, TV sets and ash trays, trucked to the site and lifted into position with the aid of a large rotor which helped to guide the 35-ton modules. The project was privately developed and economically sound.⁶⁹

⁶⁶Building Systems Information Clearinghouse's Manufacturers' Compatibility Study, Stanford, Cal., 1969 (?), provides data on structure, lighting/ceiling, HVAC, and partitioning systems—their specifications, manufacturers, and compatibility.

⁶⁷BSIC Newsletter, op. cit., Spring 1969, p. 23.

⁶⁸Architectural Design XXXVII, Mar. 1967, pp. 111-119.

⁶⁹"System Building Arrives in America," Concrete Products, Jan. 1968. The contractor later used the casting yard developed for the hotel's construction and experience gained on that job to produce low-cost housing of similar modules.

COMPARISONS: HABITAT AND PALACIO DEL RIO⁷⁰

| Project | Occupancy | Sponsor | No. Units | Cost | Cost/unit |
|-----------------|------------|------------|-----------|----------------|-----------|
| Habitat | Apartments | Government | 158 | \$13.5 million | \$85,500 |
| Palacio del Rio | Hotel | Private | 496 | \$8.5 million | \$17,000 |

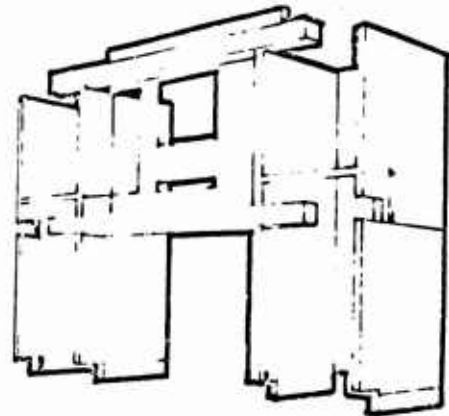
In the CAPITAL PLAZA OFFICE BUILDING for the Commonwealth of Kentucky, architect Edward Stone devised a prestressed, post-tensioned concrete floor/ceiling system which reduced the interstitial plenum depth to 27", accommodating mechanical, while providing HVAC outlets for flexible compartmentalization below.⁷¹ Open planning is possible within each floor.

The MITCHELL FRAMING SYSTEM was one of the more promising open system, precast concrete framed housing schemes, utilizing foam concrete and permitting owner completion. The system was used for a prototype Michigan housing project and was tested by HUD, the National Bureau of Standards, the National Academy of Sciences and the Army Corps of Engineers. It had minor joining problems and ran into much administrative and union difficulties.⁷²

The United States Embassy for Dublin, Ireland, designed by John Johanson, is a unique doughnut-shaped structure with a precast floor and exterior walls assembled from some of the most complex castings ever designed. It has limited capacity for "open" systems within the somewhat restricting plan configuration.⁷³

Other notable and recently completed concrete systems projects include the North Harvard (Boston) Project of Sepp Firnkas⁷⁴ and Luther Towers (Memphis).⁷⁵

These concrete systems examples are representative of American ventures, and are primarily structural, which takes them out of industrialized building in its stricter sense.



A CASTING FOR LUTHER TOWERS

Governmental Affairs

As America's population growth has intensified the demand for family housing, government response at municipal, state and federal levels has varied from lip service to legislative commitment and funding. The following programs are the most noteworthy of current administrative attempts:

⁷⁰ As with many attempts to give parallel evaluations, it is almost impossible to judge qualitatively some of the atmospheric and social aspects of individual systems projects or community developments. These tabulations regrettably show only brief quantifiable and categorical notes.

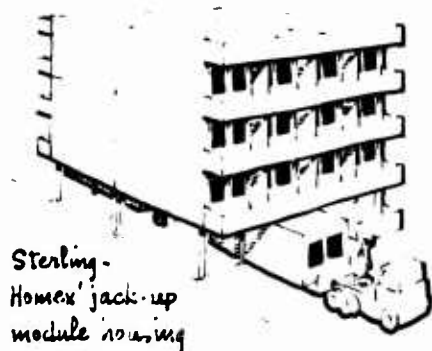
⁷¹ Architectural and Engineering News, July, 1968, pp. 68, 69.

⁷² "Tinkertoy Houses," Forum, Jan/Feb 1969, pp. 96-99.

⁷³ Progressive Architecture, XXXV 216-219, September, 1964.

⁷⁴ "Urban Housing," Architectural Record, April 1971, pp. 120-121.

⁷⁵ Ibid., pp. 122-123, 139-144.



HUD's OPERATION BREAKTHROUGH, the BRAB/GSA investigations, programs of the Department of Defense and Federal agencies, plus that of New York State's URBAN DEVELOPMENT CORPORATION.

Operation Breakthrough: Momentum gained through Housing and Urban Development's Operation Turnkey helped to mobilize for this well-conceived and federally-sponsored process which aims to double U. S. housing production in the 1970's. Announced in May 1969, Breakthrough solicited proposals for model community development demonstrations aimed to facilitate and stimulate future housing. Public and private response was gratifying for both Type A (complete housing systems) and Type B (advanced research and development contracts). Through a carefully developed evaluation, the 600 proposals were eventually narrowed in Phase I to 22.⁷⁶

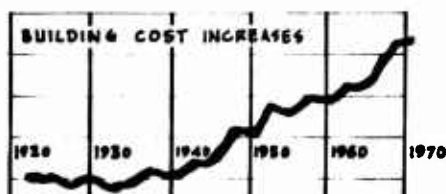
Some of the 22 consortiums selected for prototype development in Phase II are listed in Table 1.⁷⁷

⁷⁶ Breakthrough has been widely publicized; for one of the best reviews and critiques, see the American Institute of Architects' Journal, March 1971, pp. 17-22.

⁷⁷ For photographs and drawings of these and others, see Villecco and Dixon, "Breakthrough?" Forum, April 1970, pp. 50-61.

Table 1

| Consortium | Type | Form | Material | Remarks |
|---------------------------------------------------------|---------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Boise Cascade | Townhouses, garden apartments "mid-rise" | Boxes, panels | Wood and steel | Special lease-purchase and other financing arrangements were developed |
| National Homes | Highrise, up to 24 stories | Boxes up to six stories, then a conc. frame | Light fireproof materials, spray & foam walls and floor on corr'd iron | Vacuum sewage disposal, reducing water supply |
| Pemton, Inc. | Apartments up to 3 stories | Boxes | Stress-skin plywood | |
| Rouse-Wates, Inc. (British) | Highrise apartments | Floor & walls with cast-in-place joints | Concrete, precast | Like most European large-panel systems, much site finishing is required |
| Module Communities, Inc. (using Tracoba, a French syst) | Townhouse, garden & high-rise | Planar, similar to Wates | Concrete | |
| Henry C. Beck Co. (using Balency from Europe) | Highrise or detached housing | Planar, similar to Wates | Concrete | Suitable for high-density, large market areas |
| Republic Steel Corporation | single-family detached to lowrise apartments | Panels lightweight | Steel-faced insulated panels | Kitchen and bath cubicles to be factory assembled |
| Shelley | Highrise checker-board stacked, up to 22 stories | Boxes | Concrete | Loadbearing walled boxes lap to avoid duplication of chases, provide living decks |
| Sterling-Homex | Row houses, apartments two-story | Boxes | Wood frame | Labor agreements were negotiated for factory/site work |
| | Highrise | Boxes, with built-in corner columns | Steel frame & concrete floorslabs | A unique jacking up process, lifting the whole building as floors are inserted from the bottom |
| Keene Corp's: Townland system | Variety of apartments and other occupancies such as schools & shops | 3-story concrete frame with 3' deep concrete channels to contain earth fill & mechanical, with loadbearing modules slid in | | Stacked mechanical cores and schemes for building over and in occupied neighborhoods without displacing tenants. Could accommodate more flexibility and open planning than the other submissions |
| TRW Systems Group | Single-family detached to high-rise apartments & office buildings | Panels, shell components | Lightweight composite "sandwich" of resin, gypsum board & paper honeycomb | The unique fabrication process requires a winding of fiber around an adjustable mandrel to produce a variety of shapes and sizes (discontinued) |
| Material System Corp. (MSC) | Houses | Panelized, modular | Resin-filled fiber composite material | The company was assigned to seven out of nine sites—more than any other submission |



Analytically, eleven winning companies proposed to use a box system, ten proposed a panel system, and one a column/beam frame, combined with panels and boxes. The economics of these choices will be interesting to watch through Phase II, especially in light of two recent failures to make the box pay off by two large organiza-

tions—National Homes and Ford Motor Company. National Homes, in the panelized house business since 1940, was not able in an 18-month trial to get a box operation into the black. Ford, after investing \$1 million in Concept Environment, Inc., rejected the box as an economically feasible answer to housing.⁷⁸

The physical systems selected represent no radical departures, but the development of Breakthrough's processes, organization, cost information and retrieval, testing and evaluation, and its "instruments of cooperation"—may be of more import. In addition to these procedures the combination of all these was planned to aggregate the necessary markets for volume construction, which composes Phase III of the Breakthrough plan.

However well-conceived the HUD aims and strategies may be, the enabling funding is still extremely limited; many knowledgeable observers feel that the program cannot achieve its noble goals with the comparatively low priority financing with which it is operating.

THE BUILDING RESEARCH ADVISORY BOARD (BRAB) FEDERAL CONSTRUCTION COUNCIL (FCC) has a number of federal construction agencies in a pilot program "For promotion of the development and use of pre-coordinated standardized subsystems for buildings."⁷⁹ A look at the operations of these cooperating agencies shows a heightened interest in the systems approach as a cost- and time-saving process: The Veteran's Administration (hospitals), the U. S. Postal Service, the General Services Administration,⁸⁰ the Department of Health, Education and Welfare (HEW), the Corps of Engineers, Naval Facilities Engineering Command, the Air Force Office of the Directorate of Civil Engineering, and the National Aeronautics and Space Administration.⁸¹ The Underwriter's Laboratories and the U. S. Bureau of Labor are also deeply affected. BRAB/FCC conclusions from their preliminary studies were that:

1. Major pre-coordinated subsystems must supplant individual parts and materials as the "basic blocks" in building construction.
2. The time lapse between development of need and building occupancy—a critical cost factor—may be shortened through the use of pre-coordinated subsystems.
3. The owners/consumers (federal agencies) must aggregate their programmed needs, coordinate performance specifications and subsystems for optimum benefits.⁸²

THE URBAN DEVELOPMENT CORPORATION (UDC). Officials of UDC recognize that "most of the roadblocks to adequate housing for our urban populations are not technological; far from it. They are financial and political, and they affect the practice of architecture and engineering every day by blocking needed housing before it can even get so far as the first sketch."⁸³ UDC was created in April 1968, with something of a preamble stating that "the mechanisms of direct land purchase, private property condemnation, the overriding of local codes, and the power to issue independent bonds, are techniques that could be applied nationwide to provide housing for those who need it."⁸⁴ Six actual and two exploratory UDC schemes show the integration of European and U. S. industrialized systems, with good architectural design, to provide some large scale examples of housing groups.⁸⁵ Three new communities—at Amherst, Lysander and on Welfare Island—are also included in UDC undertakings, with commercial, recreational and industrial developments.

⁷⁸"Building Systems . . ." ENR, op. cit.

⁷⁹BRAB/FCC progress was presented in cooperation with the Producers Council, on March 30, 1971, in a Washington, D. C. conference.

⁸⁰Robert Blake, "The Language of Performance . . . An NBS Project," Materials Research and Standards, IX 3, March 1969.

⁸¹Individual programs of these agencies and branches are reviewed in Appendix B, Industrialized Building and Building Technology of , pp. B-14-B-19, B-23-B-25.

⁸²These conclusions, given on 21 April 1971, Washington, D.C., are quoted with the permission of HUD.

⁸³"Urban Housing," AR, op. cit., p. 124.

⁸⁴Ibid.

⁸⁵Ibid., pp. 124-138.

The \$112 million aggregated market of the six projects accounts for almost 4000 living units. It is only a part of the \$250 million bond issue passed early in 1971 which is allocated as follows:

| Project name or location | Living Units | Other Occupancies | Cost (millions of dollars) | Industrialized Aspects |
|--------------------------|--------------|--------------------------------------|----------------------------|------------------------------------------------------------------------------------------------------------------------|
| Rome, N.Y. | 200 | ? | \$4.2 | Stacked, prefabricated apartment "boxes" |
| Ithaca, N.Y. | 300 | ? | \$6 | Use of Swiss prefab non-vented plumbing system |
| Twin Parks NE | 523 | Day-care centers shops, a small park | \$18.3 | Market aggregation, modular dimensioning, common prefabricated stairs, windows & plumbing walls on groups of projects. |
| Twin Parks NW | 315 | Children's center | \$12.4 | |
| Harlem River Park | 1650 | School, community facilities, a park | \$75 | |
| Coney Island | 1000 | Day-care centers, commercial | \$14.3 | |

Department of Defense Industrialized Experience

The military construction agencies of the Army, Navy and Air Force have been pursuing industrialized building to a limited extent in the past, but recently have been increasing their activities in an effort to find new approaches to construction and procurement. Reductions in budgets, frequent changes in spatial requirements, sudden personnel changes through consolidation and expansion of bases, all have contributed to a concentrated program to establish the feasibility of using industrialized systems in their building activities.

ARMY—Most recent attempts by the Army to utilize industrialized systems have been with family housing and the temporary lodging quarters or 'guesthouse' projects. Along with a BOQ project at Fort Benjamin Harrison, Indiana, housing projects at Fort Meade, Maryland, Fort Leavenworth, Kansas, Rock Island Arsenal, Illinois and Grand Forks AFB, North Dakota have been initiated through two-step procurement methods. Although each solicitation encouraged the use of industrialized building, in each instance cited, the low bidder utilized conventional construction techniques. To these is added a housing project at Fort Carson procured by the one-step method. (See Chapter 5 for a discussion of one and two-step procurement.) Pre-engineered or metal buildings have had wide use for many years by the Army, with approximately \$30,000,000 worth being erected in the past 10 years. These have been primarily constructed as warehouse facilities.

One of the projects currently being conducted by the Corps of Engineers is the Air Force's FY-72 industrialized building package. Planned to include Administrative, Bachelor Officer's and enlisted men's housing, and warehouse facilities, the program will provide an opportunity for all three services to benefit from the experience gained.

AIR FORCE—The Air Force's industrialized building program began in the early 1960's when authorization for 220 units allowed the construction of prefabricated units that folded for transport and units that were in two sections to be bolted together.

A more recent 200 unit family housing project at George AFB utilizes panels and wet walls that are prefabricated in a moveable factory 18 miles from the site.

The current program of the Air Force involves a 2-step procurement of temporary lodging quarters at 23 bases throughout the country. Arranged in 4 geographic groupings, award of the 4 contracts is scheduled for September, 1971.

NAVY—The Naval Facilities Engineering Command has pursued the applicability of building systems to Navy facilities by study and actual construction. Recent activities include: 1) concrete modules which were completely finished and shipped by barge from Seattle to Alaska for erection as barracks facilities, 2) family housing units moved from an Air Force base to a Navy base and, 3) construction of several housing projects using one-step procurement.

The more significant approach the Navy has been taking, though, is more closely associated with the SCSD and URBS systems programs. After having identified systems, subsystems, and components that could potentially be used to provide EM Barracks, Bachelor Officer Quarters and Administrative facilities, it was decided to select total building systems for bidding. Unfortunately, the project bids for a pilot project were 25% over the budget of \$4,000,000 for the 1680-unit barracks and the project is now being built conventionally.

PROBLEMS AND PROSPECTS

The Problems of Industrialized Building

Even a cursory look at the state of industrialized building today reveals many problems: a lack of consumer acceptance, fragmentation of efforts, high costs, labor disputes, legalities, and problems dealing with product development, use and misuse, and obsolescence.

THE MANY FORCES OF BUILDING: The fragmented and sometimes autonomous forces shaping building today comprise one of the industry's major problem areas. Within the industry, these forces range from labor to management and from the 'brokerage' practices of some contractors to changing tastes in design. External forces include the reluctance of builders and buyers to invest in prefabricated buildings, higher insurance rates and maintenance costs, and restrictive codes and zoning regulations. All of these are influences which tend to work independently to shape architecture, rather than as coordinated parts of a smooth-running industry.

Some solutions to fragmentation may be found in project management. The organization of comprehensive teams for planning and negotiation, product development, coordination and financing, provides a strategy for realization of a workable end product, since the organization appropriately draws on all sources for the needed inputs.

DECISION-MAKING BASED ON INADEQUATE INFORMATION: Poor information access and retrieval methods may result in erroneous cost comparisons and spotty data. Many of the early prefabrication failures may be attributed to a lack of scheduling techniques (such as today's CPM/PERT), incomplete market surveys or simply incomplete analyses. With data computerization and operations simulation now being more highly developed, projects may be unified and more feasibly programmed. However, the gathering of facts on which decisions must be based continues to be a difficulty.

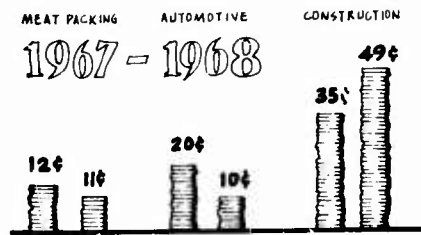
EXCESSIVELY HIGH COSTS: The building industry's lack of accord, its seasonality and the difficulty in scheduling a smooth, on-going transition from one project to the next: all contribute to costs of labor which are accelerating faster than the general inflationary trend. The price of land which is up to 20% of some total project costs, continues as a major cost factor. Interest and taxes are items that may be abated through government assistance, and product costs may be somewhat lowered through larger operations, since the aggregating of projects may save through mass-purchasing capability. However, costs are direct derivatives from many of the industry's other problems which are also examined here. If some solutions are found for those problems, costs may accordingly be lowered.

LABOR: The Battelle Report,⁸⁶ which was commissioned by the AFL-CIO in 1966 to study prefabrication's effects within the building industry, indicates the depth of concern by labor relative to the reallocation of manpower and skills. The concern is warranted, because the dynamic situation in building affects labor in many ways. Labor's worries about job security, working conditions and fringe benefits represent a large force indeed as construction becomes more industrialized.

⁸⁶Battelle, op. cit.

A former Associate General Counsel of the National Labor Relations Board (NLRB) wrote that confrontations between unions, contractors, owners and manufacturers often "center around a 'work restriction' clause in the labor agreement between the union and the contractor, or a 'product boycott' by the union at the construction site. Under current law, particularly in the application of the NLRB's 'right of control' doctrine, the role of the architect in avoiding or resolving such conflicts is all important."⁸⁷

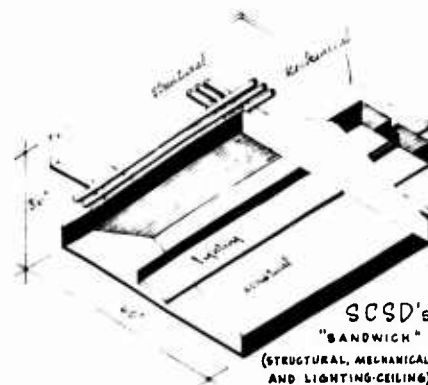
WORKER'S HOURLY INCREASES:



A prime example of one union's blocking product installation is the well-known dispute in Philadelphia, in which prehung doors had to be dismantled from their frames and reassembled by on-site union labor. Another example is the installation of shop-assembled plumbing trees in Chicago which had met with union resistance until assurance was given that like labor could be used in the factory. Such actions often are not resistance to change per se, but are protective in nature; relating pointedly to job security in a shifting industry.

Since one oft-made point of industrialized building is that costs may be reduced through the use of unskilled factory labor (which could well pose a threat to skilled labor on the site), such a movement may be expected to cause problems. However, negotiation may resolve such problems to advantage. At National Homes in Lafayette, Indiana, carpenters now install prefabricated plumbing and electrical conduit with only a supervisor from each union present for that work.

Another example of current construction labor problems is in the erection of modern ceilings. Ceilings have formerly been a visual, acoustic and fireproofing baffle which required singleminded manufacture and installation. Today, with the need for convertibility and open planning, a ceiling may have to accommodate movable (and removable) partitioning, sprinklers, electronic speakers and power sources, as well as relocatable lighting and air conditioning vents which have to accommodate to changing compartments below. Preliminary agreement between trades would seem to be a solution for jurisdictional disputes arising over which union installs portions of the ceiling complex, but such is not always the case. Scheduling and bidding of different installers continues as a source of trouble.



Finally, a problem may arise with boredom of plant workers when they are assigned the repetitive tasks which are a necessary part of mass production. Both quality of work and output declines. One obvious solution, automation, may in itself present a threat to the workers' job security. Some producers have found a solution in that after a few months, the worker may be reassigned new tasks or trained for higher skills for continued productivity.

LEGALITIES: Traditional contract documents have proven inadequate to encompass the consortium approach to industrialized building. The modification of contractual means by performance specifications is one strategy to provide legally for a sharing of responsibilities. Instead of describing a process or verbalizing what a final product has to be, performance specifications transfer much responsibility to the bidder in reviewing what the installed assembly has to do.

This transfer requires the architect to relinquish some control on design. In return, he requires the suppliers to get together to coordinate their products dimensionally and functionally. Thus, the waste and expense of cutting and fitting the different components, as well as the architect's attention to product coordination is minimized. Sub-system interfaces are additional design requirements for the supplier, spelled out in performance specifications.

Since there are many new legal ramifications and areas for litigation in industrialized building, the American Institute of Architects has cooperated with the Associated General Contractors and others in reworking their standard contract forms. These professional documents have undergone comprehensive reworking to accommodate consortia and other significant developments relating to systems.

⁸⁷ Kenneth McGuinness, writing in the AIA Governmental Affairs Review (Oct., 1969).

Another legal document being instituted is performance codes, which are vital to eliminate peculiarities of local codes which may thwart systems brought in from other locales. The automotive industry has only lately experienced localized constrictions of the kind which have long plagued the construction industry; cars would be much more expensive if they, like construction, had to be tailored to hundreds of different regional governmental requirements. Table 2 presents the status of state building code legislation.

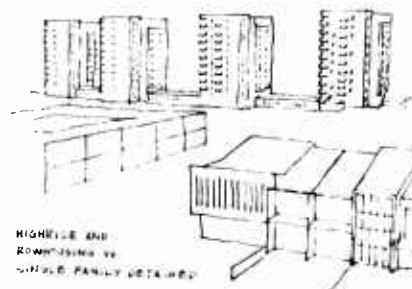
Table 2

STATUS OF STATE BUILDING LAWS - 1971

| State | Under Study | Inactive | Factory Housing Law | | Has State Code | State Code Pending | State Code Legislation Failed |
|----------|-------------|----------|---------------------|---------|----------------|--------------------|-------------------------------|
| | | | Existing | Pending | | | |
| Ala. | X | | | | | | |
| Alas. | X | | | | | | |
| Ariz. | X | | | | | | |
| Ark. | | X | | | | | |
| Cal. | | | X | | X | | |
| Colo. | | | X | | | | |
| Conn. | | | | | X | | |
| Del. | | | | | | X | |
| Fla. | | | | X | | | X |
| Ga. | | | X | | X | | |
| Hawaii | | | X | | | | |
| Idaho | | | | | | X | |
| Ill. | | | | | | X | |
| Ind. | | | X | | | | |
| Iowa | | | | | | X | |
| Kansas | X | | | | | | |
| Ky. | | | | | | | X |
| La. | | X | | | | | |
| Maine | | | X | | | | |
| Md. | | | | | | X | |
| Mass. | | | | | | X | |
| Mich. | | | | X | | X | |
| Minn. | | | | | X | | |
| Miss. | | | | X | | | |
| Mo. | | | | | X | | |
| Mont. | | | | | | | |
| Neb. | | X | | | | | |
| Nev. | | | | | plbg. | | |
| N. Hamp. | X | | | | | | |
| N. Jer. | | | | | X (m.fam) | | |
| N. Mex. | | | | | X | | |
| N.Y. | | | | X | X | | |
| No.C. | | | | X | X | | |
| N. Dak. | | X | | | | | |
| Ohio | | | X | | X | | |
| Okla. | | X | | | | | |
| Oreg. | | | X | | | | X |
| Penn. | | | | X | | | |
| R.I. | | | | X | X | | |
| So. C. | | | X | | | | |
| S.Dak. | | X | | | | | |
| Tenn | X | | | | | | |
| Tex. | | | test | | | | |
| Utah | X | | | | | | |
| Vt. | | | | | | X | |
| Va. | | | X | | | | |
| Wash | | | X | | | | X |
| W.Va. | | | X | | | | |
| Wisc. | | | | | X | | |
| Wyo. | | X | | | | | |
| D.C. | | | | | X (city) | | |

Even with the presence of four nationally-used model building codes, the lack of uniformity of standards and inconsistency of local codes has two major effects. It increases the cost of construction and inhibits innovation in construction materials and techniques. The creation of a National Institute for Building Sciences is pending in Congress. This proposed institute, which would be a non-governmental corporation, would propose nationally acceptable standards for local building codes, would provide research and technical services for new building products and techniques, and would provide standards required for use by all Federal agencies.

ATTITUDE MODIFICATION: Living habits and domestic mores are deepset, difficult to define and change, involving individual and collective preferences which tend to resist the density of highrise and row-house living (as opposed to detached single-family dwellings) and joint ownership in condominiums. These preferences affect the marketability of housing far more than other building types. In eastern Europe, some traditional housing attitudes have been overridden by government but such strong control cannot be legislated in the West. In some of Moscow's public housing, for example, tenants are not provided individual kitchens or toilets; they use communal facilities, an arrangement which would, at best, be acceptable in the West as only an interim or emergency situation.



GOVERNMENT INVOLVEMENT: At all levels—from township to international—governmental assistance is needed by the building industry for cutting red tape, for code and ordinance standardization (or circumvention), and for incentives for developers and buyers through tax reduction and subsidization of many parts of the package.

The British response to the need for housing following the great London fire of 1666 was primarily legislative, rather than industrial, in nature. Although Charles II charged Christopher Wren with the responsibility of rebuilding, few of the architect's recommendations were executed due to red tape, graft, and the strong direction of the ruler himself. However, the London Building Act of 1667 had far more effect. Prior to the fire, jurisdictional controls were fragmented and contradictory, and the Act in unifying their standards and authorities, removed those localized barriers and aided in the construction of about four types of brick houses—from "stock" plans—throughout the metropolitan area. (This is one beginning of a unified code, a critical need today.) The Act also broke the monopolizing grip of the trade guilds (the unions of today), giving the "right to work" to migrant workers. There, certain skilled-vs.-unskilled and shop-vs.-field labor disputes were resolved 300 years ago to overcome housing shortages.⁸⁸

TRANSPORTATION, a cost and logistics consideration: Maximum component sizes for shipment will vary depending on local regulations. Only a few states now permit 14' wide loads on major highways, though all dimensions may be increased for shipments via rail or water.

The "radius of economy" (or feasible shipping distance) has varied from as little as 12 miles (for some trucked concrete components) to 250 miles (for trucked wood-framed "boxes") to 950 miles (for "boxes" sent in quantity via rail).

PRODUCT DEVELOPMENT AND USE: Strong domestic tradition in home-building tends to limit the adoption of industrial techniques and materials, even in the construction of building types other than houses. For example, attempts to change from conventional wood-framed panels to other materials such as fiber-wound modules have had limited success. Also, some prototype uses of foamed concrete which could lighten foundation and structural needs indicate unresolved technical troubles. Continued research is needed in these and many other areas for product improvement.

Problems of product obsolescence include parts replacement, already a source of trouble with some California schools. For example, SCSD's plastic light diffusers which have yellowed and been broken have had to be ordered in excessive quantities (a complaint which, it might be noted, could be directed toward any material no longer manufactured but needed for a traditionally-constructed building).

A legitimate argument with systems may also occur with the misuse of a component. HVAC roof-top units, for example, are troublesome to service in severe climates while some of the more recent orthotropic roof structures have been found to deflect excessively under heavy snow. Both of these problems have been experienced by early systems installations, but the blame may possibly be placed on the specifiers choice of components.

⁸⁸Walter Bell, *The Great Fire of London, 1666*, London, 1923, pp. 154-194.

Finally, there is the problem of the thousands of uncoordinated products being independently marketed. A comparison with the automobile industry can show by contrast the inefficiency and waste of building product supply and distribution brought about by a decentralized and undirected set of operations. Today's automobile cost-volume effectiveness could never have been achieved had separate suppliers attempted to provide small independent assemblers all over the country with individual parts and components.

PROSPECTS

The gathering into consortia that is now occurring appears to be a favorable trend. The first decade of this unified approach has provided time for the development of some techniques and patterns to guide future work and has shown that there are advantages to increasing the scope of operations. While bigger cannot always be equated with better, an expansion of operations can provide access to an enlarged reservoir of resources to provide more and better buildings for more people. Like small grocers, small contractors may continue to serve local, specialized needs; but the machinery and methods needed to produce efficiently in volume in the shortest period of time would seem to be in the province of the consortia.

OPTIMIZATION OF PRODUCTS: New building materials are making further industrialization possible. An increasing use of plastics, composite materials, architectural metals and precast concrete components have all contributed to improved building techniques.

Product design, fabrication and site assembly move toward enlarged, more complex, but better coordinated components, as basic building blocks. Efforts to provide flexibility and individuality in buildings have resulted in computerized matching processes for subsystems, with a corresponding decrease in wasted materials and completion time.

DESIGN: While a majority of successful prefabricated projects have utilized panelized components, an increasing number of producers are trying "building with the box." Most "boxes" are designed for almost complete prefabrication, minimizing site work.



Only a limited amount of attention has been given to techniques for reducing the physical volume of a modular box during transportation. Some answers may be found in 1) canted walls of boxes for stacking and anchoring capability; 2) hinged panels, permitting flattening for hauling; and 3) telescoping or sleeved rooms, providing a compaction for storage and shipment.

Some designers feel systems may develop next in the direction of lighter-weight structures, including suspension, tent and pneumatic enclosures. It is possible to utilize the efficient "software" of thin-skinned building envelopes in future shelters for campuses, superblocks and other large scale developments. A kind of "stressed skin" enclosure utilizing compressed air for total or partial support, "balloon" structures hold great promise for enclosing a maximum volume with a minimum of structure. Several types have been constructed with plastic fabric membranes, with double-layered "skins," and with various combinations of reinforcing ribs and struts.

Examples of inflated structures are the DEWS radomes developed for DOD by Walter Bird, who pioneered work in inflatable structures. These "balloons" have withstood extreme arctic temperatures and windstorms over a period of several years. They fostered research which has culminated in the three different types of air structures of the Osaka World's Fair, the largest of which (the U. S. pavilion) spanned an area far larger than two football fields.

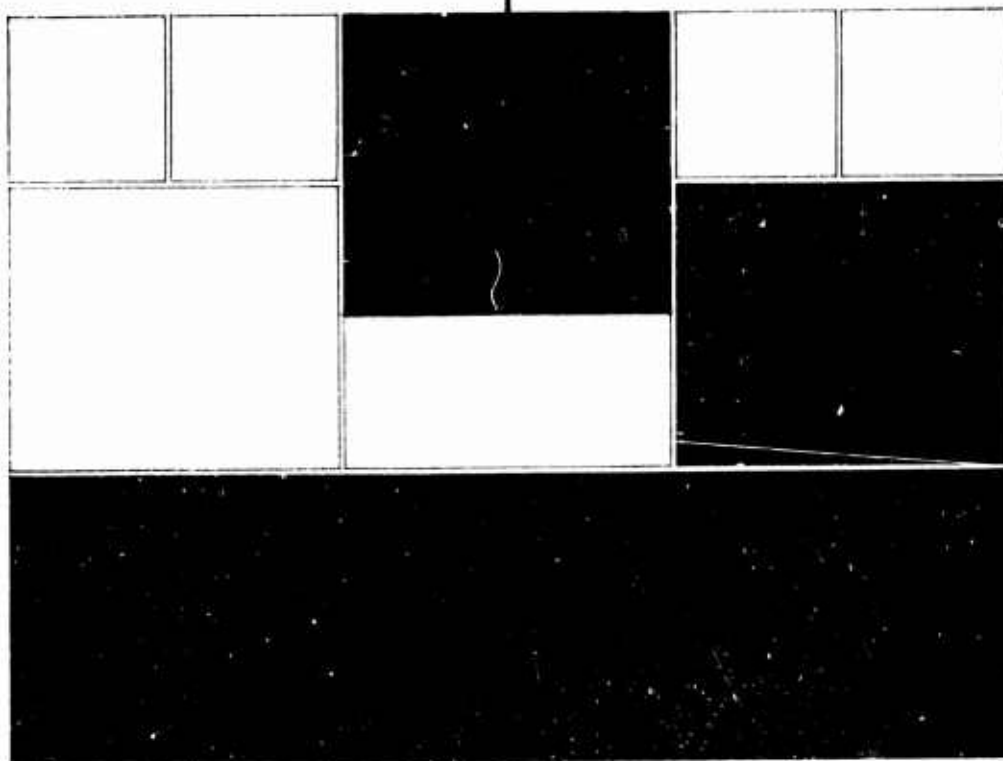
Construction's Seasonality is Reduced

The capacity to work protected from rain and the cold, either in a factory or in a project gotten under cover in minimal time, can effect savings for the owner and more continuous schedules for labor. Minimizing seasonal fluctuations is a cardinal rule of mass-production.

Mechanical developments (except for automated manufacturing processes) have shown little change in some years, and since mechanical/HVAC/electrical/plumbing costs comprise an increasing percentage of building costs, some basic research is in order. Further development of the heat pump and of solar radiation concepts may prove beneficial. Laser transmission of electric power might one day simplify traditional wiring practices, while the recycling of wastes could help to eliminate (or at least decrease) the "umbilical" type of disposal systems now common.

CONCLUSION

Despite its many problems, industrialized building continues to expand and, some feel, offers one of the best approaches for solving the critical building needs of today. The extent to which these needs include facilities on U. S. military installations is the subject of the remainder of this volume.



study procedures

3

INTRODUCTION

The study procedures followed during the course of this investigation paralleled the sequence of work objectives defined in Chapter 1. This chapter provides a detailed description of the approach followed in 10 of the 17 objectives cited.*

DESCRIPTION OF STUDY PROCEDURES

Objective 3: The identification of all industrialized building system manufacturers in the continental United States.

Industrialized building firms were classified according to the following service-product categories:

1. ARCHITECT/ENGINEER: a firm which designs, and/or describes for procurement, projects which utilize industrialized building.
2. CONSTRUCTION MANAGER: a firm which plans, coordinates and manages the constructing of projects which utilize industrialized building.
3. SUBCONTRACTOR: a firm constructing conventional portions of projects which utilize industrialized building, and/or a firm which assembles and erects industrialized building subsystems on projects which utilize industrialized building.
4. SUPPLIER/MANUFACTURER: a firm providing one or more industrialized building subsystems on projects which utilize industrialized building.

The services and products in each category are necessary to the provision of a complete building and are procurable independently in the marketplace. Since firms providing the services and products necessary for portions of a building are identified separately in the latter two categories, more than one firm may be required from each in order to provide a complete building.

A listing of the firms belonging to each of the aforementioned categories, along with information about their associated services and products, was necessary in order to generate a listing of available industrialized building systems. A tabulation of 1200 such firms, with addresses, was obtained from industry consultants**and used as a mailing list to solicit additional product information.

Objective 4: The development of a detailed questionnaire soliciting information on the design, production, and procurement characteristics of each firm's product

Separate questionnaires were developed for each of the aforementioned service-product categories.

Special emphasis was given to the preparation of the manufacturer/supplier questionnaire since extremely detailed information on industry's available systems had to be obtained for subsequent evaluation purposes. This questionnaire (found in Appendix G) included questions relating to production capability, production volume requirements, procurement preferences, physical and performance characteristics of each firm's product, and specific projects in which the product was utilized.

The surveys were mailed to 665 manufacturer/suppliers, 250 architect/engineers, 100 subcontractor/erectors, and 30 construction management firms. The survey was conducted during the period March 15 to May 15, inclusive. An overall response rate in excess of 47 percent was obtained in the supplier-manufacturer category.

Objective 7: The creation of a detailed description of programmed military construction over the next 5 years.

As a matter of policy, the Army maintains long range and intermediate range building plans. In the long range plan, building needs are projected over the next 20 years, while in the intermediate range plan, requirements are projected over 5 years. In view of the fact that plans are continually changing (Army plans are revised on a quarterly basis), the intermediate range plan (hereinafter referred to as the five-year building program) was chosen as the description of the forthcoming Army building program for the purposes of this study.

*The remaining seven objectives were ancillary to the central purpose of the study and are fully described in a supplementary portion of the text.

**The initial listing of firms was compiled by Building Systems Development Inc. under Contract No. DACA88-71-0004. See Appendix for a listing of the firms.

Objective 8: The development of criteria for ascertaining the acceptability of industrialized building systems for military construction projects.

A feasible industrialized building system was defined as one embodying the following characteristics:

1. **DESIGN COMPATIBILITY:** the industrialized building system's characteristics match the design requirements for the Army's building project.
2. **PRODUCTION COMPATIBILITY:** the industrialized building system's requirements for successful competition with conventional building match the characteristics of the Army's building project.
3. **PROCUREMENT COMPATIBILITY:** the industrialized building system's contracting procedures match at least one acceptable procurement method in existing Army regulations.

DESIGN COMPATIBILITY

Since a building project is a collection of building types, the design requirements were developed by building type instead of building project. Furthermore, only those building types constituting a sizeable percentage of the five-year dollar value of planned building construction were considered to be of major interest. The specific types considered were:

1. Enlisted Men's Barracks
2. Bachelor Officer's Quarters
3. Administrative Buildings
4. Covered Storage Facilities (Warehouses)
5. Tank and Automotive Maintenance Facilities
6. Classroom Type Training Facilities.

The design requirements for these building types were extracted from the Department of Defense Manual of Construction Criteria, DOD No. 4270.1-M, March 1, 1968 Edition (hereinafter termed "DOD criteria") in the following manner:

1. the six major building types were divided into parts corresponding to the subsystems presently available in industrialized building systems; then these subsystems were subdivided into elements and characteristics for which design requirements were considered necessary;
2. the elements and characteristics presently governed by the DOD criteria were identified along with their DOD design requirements, when these existed.

Realizing that the DOD criteria would not specifically cover every element and characteristic considered necessary and that the Corps' Guide Specifications were too detailed to be workable, performance standards for each of the elements and characteristics were developed. These standards were predicated upon:

1. DOD criteria;
2. requirements of nationally-recognized code authorities, trade associations and professional societies;
3. results of similar private and public studies, conducted for similar purposes for similar building types;
4. minimum standards for Federally-financed housing;
5. current technological and production capability of private industry;
6. professional judgment of industry consultants.*

These performance standards served as a supplement to the DOD criteria in determining design compatibility.

The characteristics of industrialized building systems were solicited from industry, by questionnaire, as follows:

1. the questionnaire was divided into parts corresponding to the same subsystems used in developing the Army's design requirements;
2. for each firm's subsystem, information about its physical and performance characteristics was requested in a form suitable for direct comparison with the DOD criteria and the performance standards.

*The performance standards were developed for CERL by the Engineers Collaborative, Ltd. under Contract DACA88-71-C0003. A copy of their report, showing the performance standards and the assumptions governing their development, is in Appendix A.

PRODUCTION COMPATIBILITY

The important parameters for production compatibility were considered to be:

1. the size of building project.
2. the transportation distance.

The size of project was defined as either the dollar value or the square footage of construction, and the transportation distance was defined as the distance between the project location and the source(s) of the industrialized building.

The information obtained with respect to the Army's building program was:

1. the location of the building projects.
2. the dollar value of construction, on a fiscal year basis, with respect to each of the six major building types previously identified.

The information source was the Army's five-year building program.

Realizing that projects in the Army's building program might not be of sufficient size and that the possibility existed of combining projects with those of other Armed Services, the same information was obtained from the Navy's and the Air Force's five-year programs. In addition, estimates of non-military building programs* were made in the vicinity of four selected Army bases in order to get some idea of the total potential market in those areas.

The pertinent information obtained from industry was:

1. size of project required to justify a production run (or submittal of a competitive bid);
2. location of plant(s);
3. distance over which the product could be transported and still be competitive with conventional building;
4. list of industrialized building projects completed or underway.

A questionnaire was used to obtain this information.

An industrialized building system was considered production compatible if:

1. the size of the building project was at least as large as the size of a project required to justify a production run;
2. the transportation distance was no greater than the distance over which the product could be transported and still be competitive with conventional building.

In determining production compatibility, only two classes of comparison were considered to be important for the study:

1. the immediate prospects (FY 73 groupings);
2. the aggregated prospects (five-year groupings).

The comparisons of FY-73 projects provided a basis for selecting pilot projects for immediate implementation, while the comparisons of five-year groupings suggested possible modifications to the Army's five-year building program to increase the opportunities for advantageous use of industrialized building systems.

In the information obtained from industry, there were estimates made by the firms of the conditions under which they could compete with conventional builders. In an effort to obtain some idea of their ability to compete on an initial cost basis, a follow-up questionnaire was sent to selected industrialized building firms in order to obtain cost data.

*The estimates were prepared for CERL by McKee-Berger-Mansueto, Inc. under Contract DACA88-71-C-0012.

PROCUREMENT COMPATIBILITY

An industrialized building firm was considered to be procurement compatible if it would offer its service(s) and/or product(s) directly to the Army and if at least one of the ways it would offer them was permitted by Army regulations.

The methods of procurement permitted by the Army regulations were taken from the Armed Services Procurement Regulations (ASPR).

The methods by which firms were willing to offer their services and/or products for procurement were obtained by questionnaire. The firms were questioned about their willingness to accept Army-permitted methods as well as other known methods.

Objective 9: The application of acceptability criteria to industrialized building systems

The determination of the feasibility of each firm was made by three consecutive comparisons: namely;

- | | | | | |
|------------------------------|---------|----------------------------------------------------------------------------------------------------------------------------|------|---------------------------------------------------------------|
| 1. DESIGN COMPATIBILITY | Compare | the characteristics of an industrialized building system | with | the design requirements of a particular Army building project |
| 2. PRODUCTION COMPATIBILITY | Compare | the requirements of an industrialized building system in order to successfully compete with a conventional building system | with | the characteristics of a particular Army building project |
| 3. PROCUREMENT COMPATIBILITY | Compare | the methods by which an industrialized building system can be procured | with | the Army procurement regulations |

A graphical presentation of the application of the criterion to identify a feasible industrialized building system is given in Figure 1.

Objective 10: The establishment of a criterion defining the amenability of projects to industrialized construction.

It is generally accepted in conventional building that increasing competition engenders proportionate reductions in total construction costs. Analogously, this study assumed that the greater the number of feasible industrialized building systems available for a given building project, the greater the likelihood that industrialized building could successfully compete with conventional building.

Objective 11: The application of the project amenability criterion to all 82 construction zones to generate a rank-ordering of promising building projects.

Selecting the most promising projects required the identification of all feasible industrialized building systems available for each Army building project. Consequently, the criteria defining the production compatibility of industrialized building systems also served to generate a list of Army building projects having at least one feasible system. The amenability criterion (Objective 10) consisted of counting the number of feasible systems for each building project. The rank-ordering was then generated by arranging the projects in order from those having the highest to those having the lowest number of feasible systems.

Objective 12: The analysis of procurement methods currently utilized by industrialized building.

The methods by which a firm would offer its product for procurement were obtained by questionnaire. The listing was obtained from the replies given by firms having feasible systems for the most promising projects. There were six different procurement methods on the questionnaire sent to industry. For each feasible system on each project, each acceptable procurement method was recorded. In this way, a listing of alternative procurement methods for each project was generated.

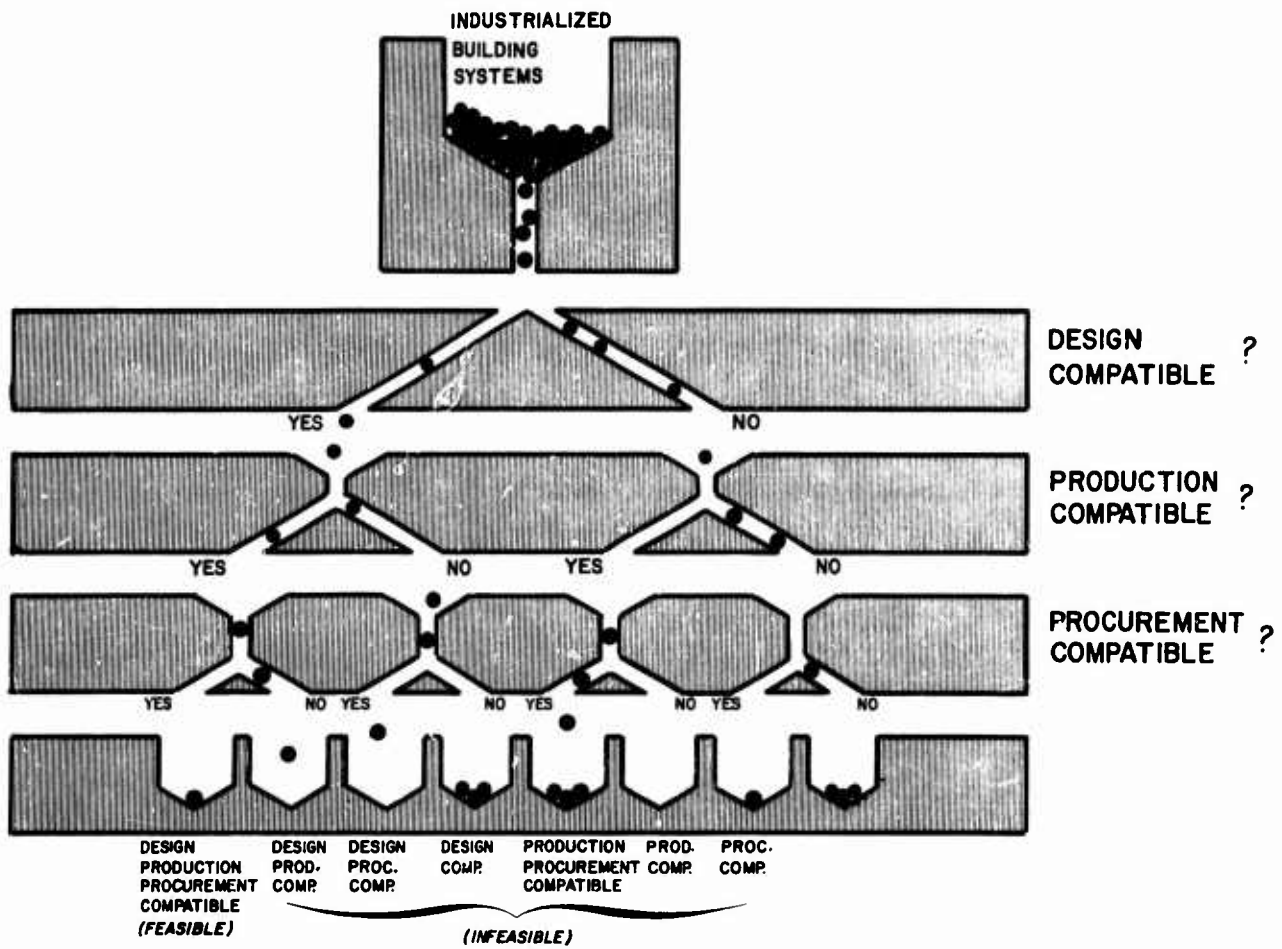


FIGURE I

Objective 13: The analysis of procurement methods facilitating the incorporation of industrialized building into the MCA program.

The best procurement method was considered to be the one that enabled, for a given project, all feasible industrialized building systems to be procured. Consequently, the greater the percentage of feasible systems which could be procured on a project with a particular method, the more promising the method. This was the criterion used in the study. Applying the criterion consisted of counting, for each project, the number of feasible systems procurable by each of the procurement methods. Generating the listing required recording, for each project, the procurement method(s) associated with the largest number of feasible industrialized building systems.

Objective 14: The collection of actual industrialized building cost data.

Projects having buildings considered to be similar to the six major Army types were selected from the lists of projects (completed or underway) provided in response to the initial questionnaire. By selecting projects at random, it was possible to obtain representative data unbiased by the tendency to disclose only low cost examples of firm performance. Over 90 percent of the firms solicited responded, providing detailed cost data on 84 projects built within the past 3 years.



design compatability
4

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CHAPTER 4 — DESIGN COMPATIBILITY

CONCEPT

In order to determine if a particular industrialized building will satisfy the design requirements for any of the six selected building types, both the 'off the shelf' characteristics of the industrialized building and the design requirements for the Army building type were identified. When a matching of those standard product characteristics and their equivalent design requirements occurred, that industrialized building was classified as Design Compatible. When design compatibility was not achieved, those building characteristics which were most frequently in non-compliance with DOD Criteria were studied to ascertain if the corresponding design criteria were generally more stringent than those to which industry's 'off the shelf' products were produced. Where these criteria are maintained at present levels, this will permit industry to be informed of inadequacies in their products, enabling it to bring them into compliance with DOD Criteria.

MEASURES OF DESIGN COMPATIBILITY

Building Characteristics—To obtain a list of building characteristics for each firm's industrialized product, subsystem or system, the survey technique of a mail questionnaire was used. Besides containing information from each firm about its production and procurement capabilities and procedures, the questionnaire extensively surveyed the firm's product's physical and performance characteristics. It was divided into sections corresponding to design considerations and the subsystems used in developing the Army's design requirements. Included within these building characteristics were:

- Number of stories—Due to general military policy limiting construction to 3 stories or less for reasons of economy, aviation obstacle and land availability, only systems suitable for 3 stories or less were compatible.

- Roof loads—adjusted for climate (see Fig. 2)

- Floor loads—for each building type

- Wind load—not including coastal hurricane force

- Construction classification—as used in model building codes

- Clear span—suitable for building types

- Mechanical penetration—ducts, piping, conduit—horizontally

- Stairway requirements—loads, exit widths

- Fire ratings—walls, partitions, ceilings

- Insulation value—walls, roof

- Roofing guarantees—

- Electrical standards—

Design Requirements—Comparison of the industrialized building with the project requirements requires a commonality of the measurement characteristics. Since the Department of Defense Construction Criteria Manual, 4270.1M, and its attendant technical references prescribes technical criteria for the Military Construction Program, uniform acceptable building characteristics for all Defense Components are therefore available. The desirability of a basis common to all Defense Components or Armed Services comes from the potential application of these design classifications (compatibilities) to the other Armed Services through individual project use or by inter-service aggregation of projects.

MCA PROGRAM

Selected Building Types

To obtain dollar value and area of planned building construction for FY 73-77, reference was made to applicable reports issued by the Army, Navy and Air Force. Groupings of similar buildings were then made utilizing the Army facility classes given in AR 415-28, "Department of the Army Facility Classes and Construction Categories." For example, category number 724 is Bachelor Officers Quarters and number 310 is R&D and Test Buildings. Category number 740 is community facilities—morale, welfare and recreational—interior. Because of the diversity of types of buildings in category 740 (banks, chapels, gymnasiums, open messes, etc.) subgroupings were made within the category. Table 3 contains the category numbers and descriptions for each grouping of buildings. These 30 groups are sufficiently different in function/design to warrant separate evaluations.

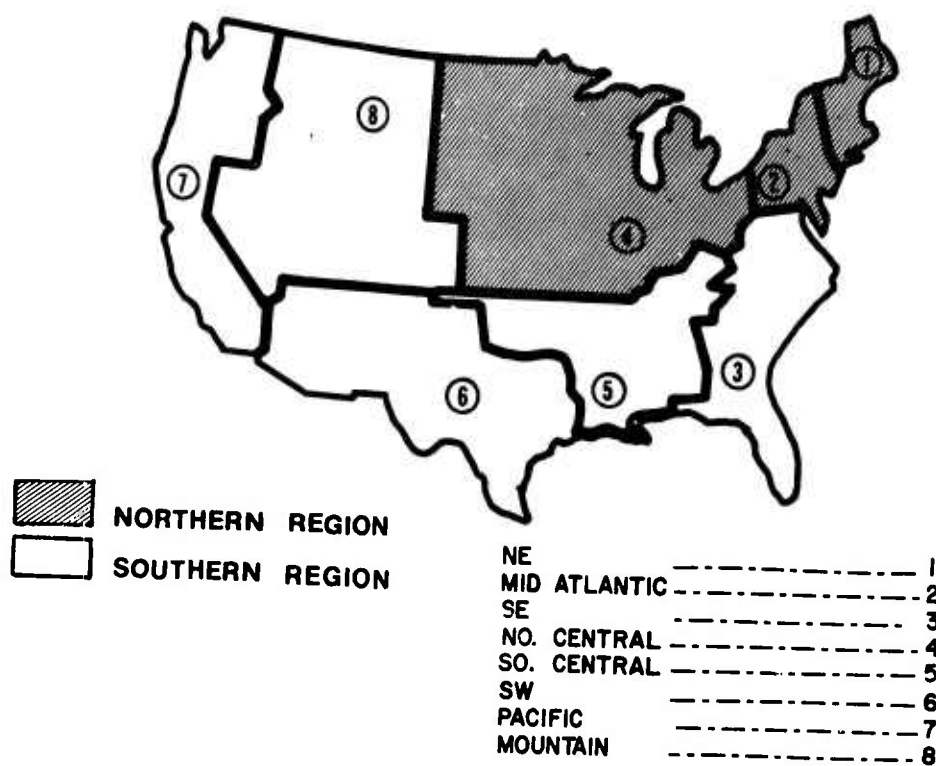


FIGURE 2

Several categories of buildings, such as hospitals, were not included in this study because of their uniqueness. Certain other categories, such as banks, museums and bowling centers, were so few in number as to have no impact and hence were not included. Still others peculiar to the Navy or Air Force, such as ship component repair shops were not included.

Of these 30 groups (types), 6 were considered to be of major interest in this study and are discussed in detail below.

Table 3

Category Numbers and Descriptions for Each Building Group

- 131 – Communications Buildings
- 141 – Operational Buildings, Fire Stations
- 141 – Operational Buildings
- 171 – Training Facilities, Classroom Type
- 171 – Training Facilities, Other than Classroom Type
- 211 – Maintenance Facilities, Aircraft
- 214 – Maintenance, Tank, Automotive Shop
- 217 – Maintenance Facilities, Electronic Equipment
- 218 – Maintenance Facilities, Miscellaneous
- 219 – Maintenance Facilities, Base Engineer
- 310 – R&D and Test Buildings
- 432 – Cold Storage, Installation
- 441/2– Storage, Covered; Depot and Arsenal; Installation and Organizational; i.e., Warehouses
- 540 – Dental Clinics
- 550 – Dispensaries or Dispensaries/Dental Clinics
- 610 – Administrative Buildings
- 721/2– EM Barracks with Mess and without Mess
- 723 – EM Mess Buildings
- 723 – Troop Housing, Detached Facilities; Administration and Supply and Battalion Storage
- 724 – Bachelor Officers Quarters
- 730 – Community Facilities, Personnel; Fire Stations
- 730 – Community Facilities, Personnel; Police Operations
- 740 – Community Facilities, Morale, Welfare and Recreational, Interior (CFMWRI); Chapel Facilities
- 740– CFMWRI; Commissaries and Exchanges
- 740– CFMWRI; Crafts, Hobbies and Work Shops
- 740– CFMWRI; Community Centers and Youth Centers
- 740– CFMWRI; Gymnasiums and Fieldhouses
- 740– CFMWRI; Libraries
- 740– CFMWRI; EM Service Clubs, NCO and Officers Messes and Clubs
- 740– CFMWRI; Post Offices

Although the original intention was to analyze the building program by fiscal year, there subsequently proved to be insufficient planned construction in each fiscal year for a particular building type in a specific geographical area to warrant such detailed analysis. FY-73 is an exception to this as it provided a basis for selecting pilot projects for immediate implementation. FY-72 planned construction was not considered since the construction documents for projects in that year are either complete or will be well underway before any industrialized procedures could be implemented as a result of this study.

Planned Construction—Army

Table 1, Appendix A (FOUO), lists the dollar value, percent of total dollar value, area and percent of total area for each of the 30 building types for the Army. The first 8 types listed account for 79 percent of the total value and 80 percent of the total area. However, 2 of these types, "310-R&D and Test Buildings" and "171-Training, Other than Classroom Type" are very diversified and will not be further analyzed. The other 6 types will be studied in detail—indeed these are the only types with sufficient value and frequency within geographical zones to warrant consideration of industrialized construction methods. These 6 types are:

- 171 — Training Facilities, Classroom type (CLR)
- 214 — Maintenance, Tank, Automotive Shop (TAM)
- 441/2— Installation Storage Facilities (STO)
- 610 — Administrative Buildings (ADM)
- 721/2— EM Barracks (EMB)
- 724 — Bachelor Officer Quarters (BOQ)

Even though these already represent over one-half of the total programmed construction, other building types are of similar character to the 6 selected and could be considered as potential supplement to the Army's nearly \$560,000,000 worth of planned construction anticipated in the 6 types. Examples of similar facilities with the selected types are:

- Training Facilities (171): aircraft trainer building, reserve center
- Maintenance, Tank and Auto (214): aircraft maintenance, weapons maintenance, machine shop, some R & D Test Facilities
- Installation Storage (441): gymnasias, National Guard armory, garages, commissaries, exchanges
- Administrative (610): headquarters facilities, flight operations
- Bachelor Officer Quarters (724): temporary lodging quarters, dispensaries, clinics

Total Armed Services Needs

Tables 2 and 3, Appendix A (FOUO) list for the Navy and Air Force respectively the dollar value, percent of total dollar value, area and percent of total area for each of the building types that were listed in Table 1 for the Army. Of the 6 major types selected from the Army table for further study, 4 appear in the first 8 of the Navy table and 3 appear in the first 8 of the Air Force table.

Table 4, Appendix A (FOUO) shows all of these data plus combined totals for the 3 services. For the 3 services combined, the 6 selected major types represent 54 percent of the total dollar value and 62 percent of the total area for all 30 types. Only planned permanent construction in the 48 contiguous states was considered.

FIRM CLASSIFICATION RESULTS

Through the use of computer-aided data sorting, a list was generated providing the following information:

1. Name of Firm
2. Those DOD Criteria with which the firm's product complies.
3. Those DOD Criteria with which the firm's product does not comply.
4. Those DOD Criteria on which a judgment could not be made due to partial completion of the particular questionnaire.
5. Those DOD Criteria which do not apply to the firm's product.

Because a significant number of firms partially completed a particular section of the questionnaire that included DOD judgment criteria, CERL has expanded the base number of potentially DESIGN COMPATIBLE classified firms. Barring any NON-COMPLIANCE classification, if fewer characteristics are classified NOT JUDGEABLE than DESIGN COMPATIBLE, that firm is considered DESIGN COMPATIBLE.

Certain DOD Criteria are more stringent for some building types than for others. A firm's product may, for example, comply with the floor live load requirements for Bachelor Officer Quarters and Enlisted Men's Barracks, yet not comply with that for Administrative buildings. As long as the product met all other requirements applicable to all building types, the product would be classified as Design Compatible-BOQ/EMB. Classifications also include Design Compatible TAM/STO and Design Compatible-ADM/CLR, which recognize the particular requirements of Tank and Automotive Repair Facilities (TAM), Installation Storage Facilities (STO); Administrative Buildings (ADM), and Classroom-type Training Facilities (CLR). A supplementary category establishes whether the product is suitable for the southern or northern regions, recognizing snow loads and thermal conductivity.

The listing of each design compatible firm appears in Appendix B (FOUO) and, in summary, includes the following results. Based on 270 useable questionnaires submitted by the industry the results of the comparisons of each firm's product with the DOD Construction Criteria were as follows:

| | |
|--------------------|------------|
| Design Compatible | |
| All building types | 51 firms |
| Design Compatible | |
| EM Barracks - BOQ | 52 firms * |
| Design Compatible | |
| Classroom Admin. | 45 firms* |

*In addition to 51 firms design compatible for all building types.

Investigation of the significant frequency of product characteristics which do not comply with current DOD Criteria reveals the following (see following diagram, page 2-41):

1. Approximately 30 percent of the roof structures are not designed to resist snow loads over 20 psf, making them acceptable for southern regions only (with a few exceptions in the northern region).
2. Wind loads of 30 psf or greater were not accommodated for in 20 percent of the structures.
3. DOD criteria allows for the use of combustible buildings for facilities of relatively small size and light hazard use. This has been liberally interpreted to include most facilities in the category of BOQ, EMB, ADM, and CLR. A preponderance of the systems are basically wood, due to the significant number of apartment and home manufacturers. Following the liberal interpretation, CERL classified the 240 combustible systems as complying with construction classification requirements.
4. 110 firms did not have sufficient clear span to meet STO or TAM requirements.
5. The thermal 'U' value of 42 firm's exterior wall systems are suitable only for the southern regions.

RECOMMENDED CRITERIA – DESIGN COMPATIBILITY

Identification of DOD Criteria applicable to industrialized building elements and characteristics revealed a scarcity of requirements for many elements. To rectify this and provide a set of standards for consideration for application to industrialized building, recommended performance standards were developed by industry consultants.** Although the recommended standards do not reflect final approval of the Department of the Army, they are based upon a broad range of accepted industry standards. Briefly they include:

1. DOD requirements
2. National code authority and professional society requirements
3. Federally financed housing standards
4. Professional judgment

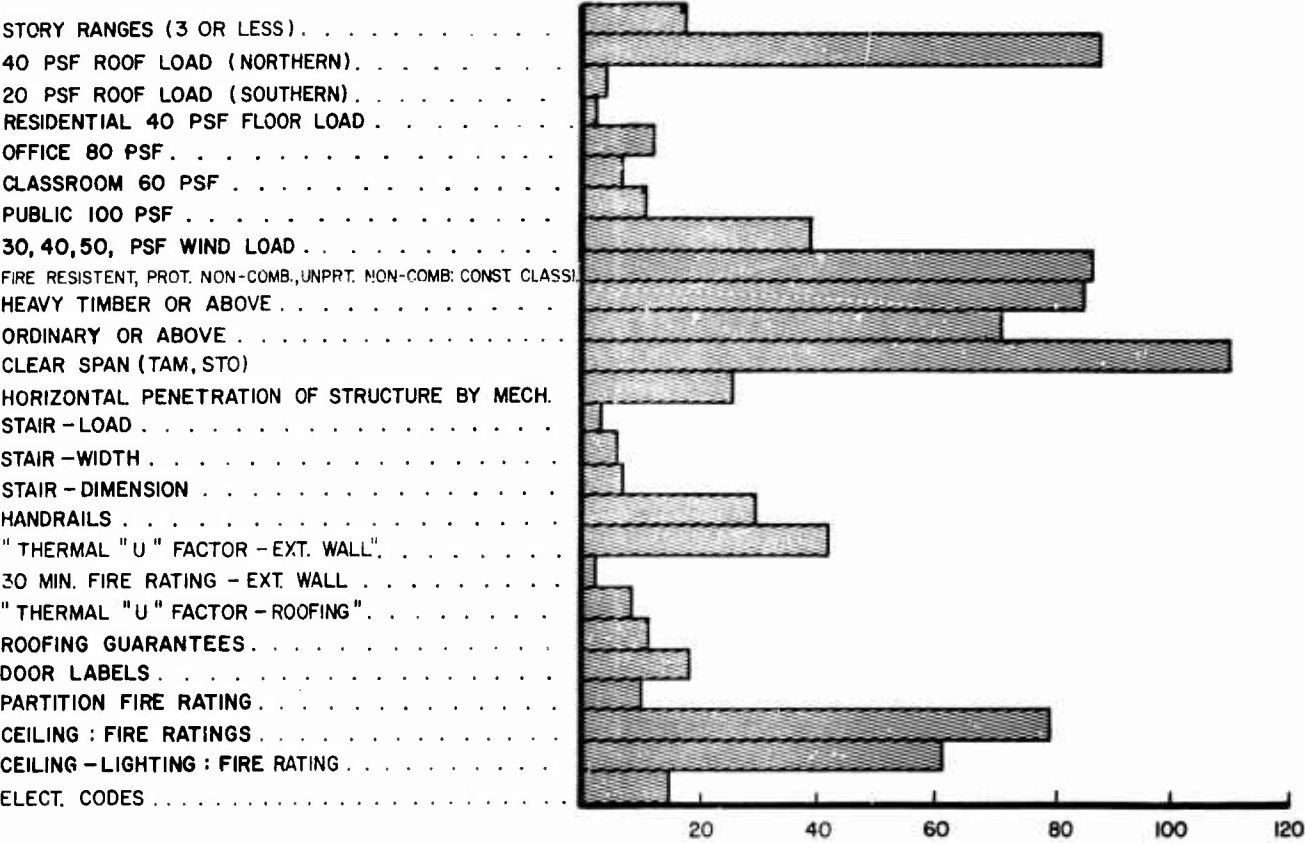
A listing for each firm, similar to that for the DOD criteria comparison was generated showing comparison of each firm's product with the recommended criteria. The following lists the characteristics compared:

Number of stories
Roof live load
Floor live load
Residential, classroom, Office
Seismic load
Wind load
Clear span
Mechanical penetration
Stairway live load, width
Exterior walls
Thermal insulation
Fire resistance
Water penetration
Air infiltration
Roof thermal insulation
Roofing guarantees
Partitions
Wiring ease
Labeled doors and frames
Sound transmission
Fire resistance
Flame spread
Stability
Ceilings
Lateral support
Integration with subsystems
Fire ratings
Mechanical systems noise level
Electrical code compliance
Model building code compliance

*In addition to 51 firms design compatible for all building types.

**The Engineers Collaborative, Ltd., Contract DACA88-71-c-0003.

NON-COMPLIANCE FREQUENCY DOD CONSTRUCTION CRITERIA



NUMBER OF NON-COMPLYING FIRMS

Non-compatibility with the recommended standard resulted primarily from the windload requirements, clear span suitability for Storage and Maintenance buildings, the ability of the ceiling system to provide lateral support for the partitions and to inter-relate to other subsystems (fire protection, HVAC, partitions, plumbing and structural). (See following diagram.)

ANALYSIS OF FINDINGS

The reasons for the number of firms classified as incompatible compared to the total number responding to the questionnaire (270), warrants some analysis, both factual and speculative. The factors contributing to non-compatibility are assessed as follows.

1. **CHARACTERISTICS OF PRODUCT**—Approximately 40 percent of the firms identified as industrialized building firms are apartment and single family home builders utilizing industrial processes. Many of these firms were limited to BOQ-EMB building type application.

2. **FEW NON-COMPLIANCES**—To avoid making subjective and perhaps inconsistent judgments, the firm was required to meet DOD Criteria in ALL areas that were applicable to its product. For example, of the 204 firms responding to the question relating to the thermal conductivity of their exterior wall systems, 90 complied with DOD northern climate criteria, 44 did not (therefore removing them from the compatible classification for northern project zones), and 70 did not answer (placing them in a not judgeable classification for that section). (See page 2-39.)

3. **CURRENT PRODUCT CHARACTERISTICS**—In order to establish the present capability of the industry, the performance of their products does not reflect what criteria they could meet if the product were altered. In the example (No. 2 above), if more insulation was added to the firm's standard or 'off the shelf' product, a higher number of firms would be able to comply with the thermal requirements.

4. **AVAILABILITY OF DATA**—Data on the product may be lacking for several reasons: 1) the product has not been tested to provide performance data, or 2) the person completing the questionnaire was not aware of data that existed.

5. **SURVEY TECHNIQUE**—Typically, a questionnaire of this length and of this complexity can expect to cause some inaccuracy, inconsistency and variation in interpretation. Because this information was obtained by mail questionnaire, the validity of the data received from industry had to be assumed. Confirmation of each manufacturer's data and resultant design classification is highly desirable before a listing of these classifications is released.

6. **OTHER STUDIES**—Frequent inability of one specific type of industrialized building, the pre-engineered building, to meet military design criteria is confirmed by the results of a testing program of the U. S. Naval Civil Engineering Laboratory at Port Hueneme, California. Of 32 buildings tested, only 14 met structural and other standards of the Uniform Military Requirements Criteria.

CONCLUSIONS

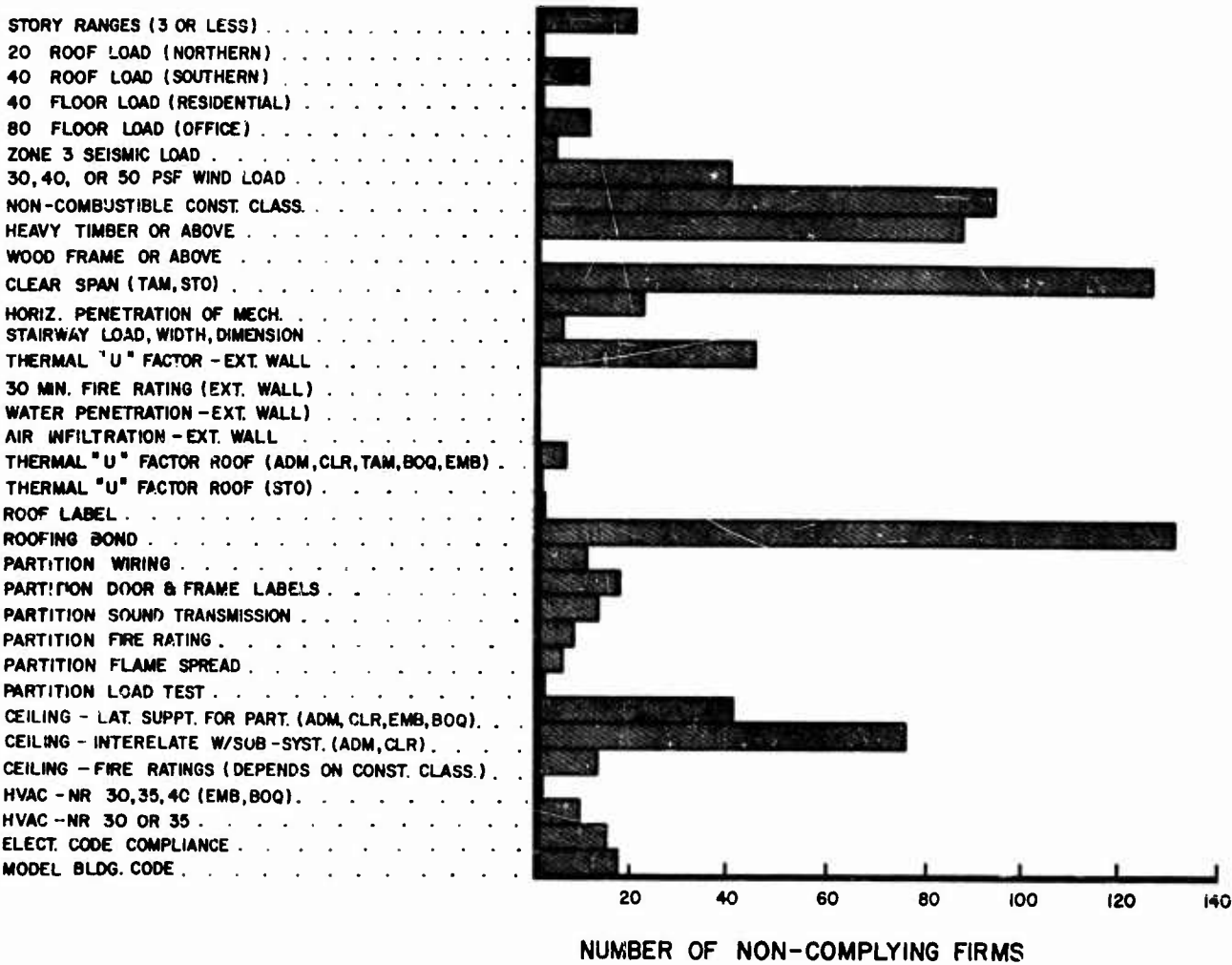
Although the results of this comparison of criteria and characteristics revealed that only 30 percent of the firms surveyed had products conforming to DOD Criteria, this represents a sufficient number of systems by itself to provide a competitive situation in selected locations and building types. Additionally, many of the products are able to be brought into compliance, enlarging the potential source of prospective bidders.

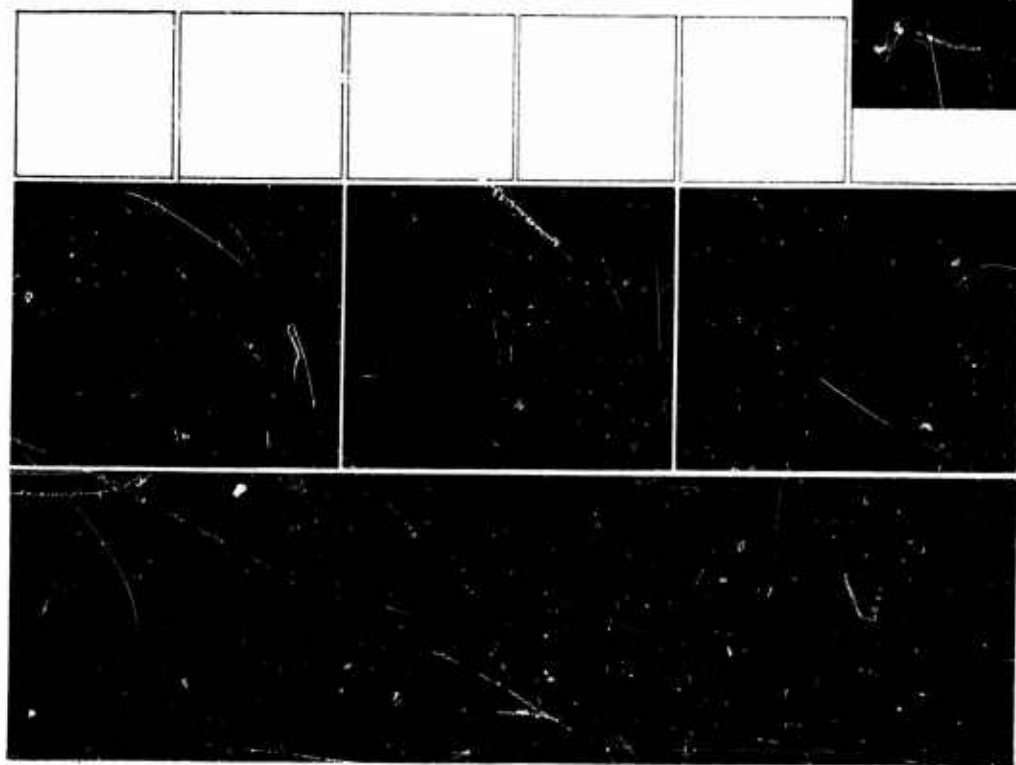
Deputy Assistant Secretary of Defense (Installations and Housing) Edward J. Sheridan in a 9 April 1971 memorandum to the Assistant Secretaries of the Army, Navy and Air Force (I & L) included the recommended Defense position toward building systems. Proposed to be included in the DOD Instruction 4270.1-M, Construction Criteria Manual, now being revised, this interim action briefly contains:

1. Encouragement of the use of building systems commensurate with economic justification.
2. Definitions
3. Requirements of full conformance with the provisions of the Construction Criteria Manual.
4. Provisions for design and components to be standard products of the industry, requiring no further research or development.
5. Requirement for certification of the uncertainty of a facility's tenure before the feature of relocatability may be specified.

Performance evaluation of industrialized buildings demands that criteria be in such a form that the desired performance, physical tests or other evaluative techniques are clearly described. The difficulty experienced in making direct comparisons of DOD Construction Criteria with industrialized building characteristics was indicative of a history of conventional construction application. Since nationally accepted model building code requirements are becoming increasingly performance oriented, their recognition, together with the addition of physical descriptors omitted by DOD construction criteria will facilitate the implementation of industrialized building.

NON-COMPLIANCE FREQUENCY
RECOMMENDED CRITERIA





procurement compatability

5

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CHAPTER 5 – PROCUREMENT COMPATIBILITY

INTRODUCTION

Present governmental regulations applying to the procurement of construction have been established primarily for application to conventional methods of construction and traditional relationships between owner, architect and contractor. This chapter examines the acceptability of procurement methods used by individual industrialized building firms with special reference to current Armed Services procurement regulations. The primary question to be answered is: under present army policies, can a firm's industrialized product be procured? Emerging associations or contractual relationships of professional design, management and manufacturing firms will also be explored to determine the effect of Government procurement procedures on the accommodation of these changes in the building industry, and the utilization of the most recent concepts in Industrialization of construction. The procurement methods established by the Armed Services Procurement Regulations and those utilized by industry will be discussed to provide a basis for comparison and subsequent determination of compatibility. Finally, a list of manufacturers will be generated that will contain those firms whose present procurement methods are compatible with existing procurement regulations.

ARMED SERVICES PROCUREMENT REGULATIONS

Armed Services Procurement Regulations establish for the Department of Defense uniform policies and procedures relating to the procurement of supplies and services and all purchases and contracts made by the Department of Defense which obligate appropriated funds.

As a general policy, these regulations are not intended to stifle development of new techniques or methods of procurement. When required in the best interests of the Government, deviations may be proposed to the Assistant Secretary of Defense (Installations and Logistics) through procurement channels. This provides a vehicle for change, however, general policy requires all procurements be made on a full and free competitive basis with the use of firm fixed price contracts to the maximum extent possible.

CONTRACTURAL RELATIONSHIPS

General

Directly related to the methods of procurement that are compatible and appropriate is the composition of the construction team. It is apparent that in this area the greatest change is taking place in private industry. The nature of industrialized building is determined not only by the manufacturing process but by the management system. Successful industrialized projects completed to date have been realized not by the traditional, sequential, one at a time movement through the projects by each member, but by a simultaneous involvement of all members throughout the projects.

The fragmentation of the building industry exists and is nurtured by a piecemeal approach to project process, i.e., the 'taking of turns' by each member of a project. However, we are beginning to see collaboration in the form of joint ventures and total management firms which is breaking down traditional relationships of industry members (Fig. 3).

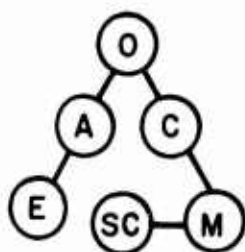
This can be most clearly seen by the makeup of many of the sources of building systems architects with an enlarged staff of engineers, construction firms who are supplementing their firms with architects and engineers, manufacturers who are hiring all three, and developers whose firm character is determined by those already mentioned as well as a previous history outside the construction industry. Thus, industrialized building entails management reorganization paralleling technological changes. We already have a powerful technology. Implementation of it through marketing, management and capital investment will make possible overall stability and feasibility of industrialization. Therefore, as we see industry collecting its forces into groups containing firms that are presently contracted with individually and with differing forms of contracts, the flexibility of procurement regulations will be thoroughly exercised in the application to these new relationships.

— LINK DENOTES A CONTRACTURAL AGREEMENT

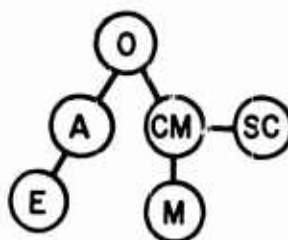
◻ SHADED AREA DENOTES SINGLE ORGANIZATION

◻ EITHER SINGLE ORGANIZATION OR CONTRACTURAL AGREEMENT

O OWNER
A ARCHITECT
E ENGINEER
C GEN. CONTRACTOR
SC SUBCONTRACTOR
M MANUFACTURER / SUPPLIER
CM CONSTRUCTION MANAGER



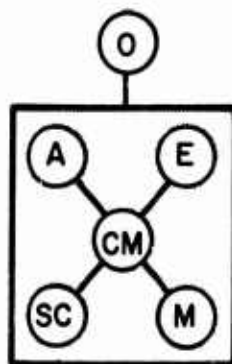
1. TRADITIONAL



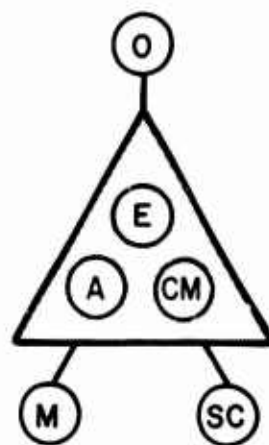
2. SINGLE CONSTRUCTION MANAGEMENT



3. PACKAGE



4. CONSORTIUM



5. SINGLE PROJECT MANAGEMENT

FIGURE 3

Traditional Relationships

The traditional process has been the one utilized for nearly all of the construction procurement in Government agencies. The Army, for example, utilizes the Corps of Engineers as a contracting agency acting on behalf of the installation to procure design and engineering services then in turn to administer the bidding, award, and enforcement of the contract. This is graphically expressed in Figure 4.

The architect/engineer is selected from available qualified firms using a negotiated contract for design services which defines the scope of the work to be performed based on the complexity of the proposed facility. Given the design guidelines of the building program, DOD Construction Criteria, and supplementary design criteria of the Corps of Engineers, the A/E provides an acceptable solution to the facility requirements using open subsystems and conventional materials. This design, in the form of construction documents, is advertised for bid to attempt to receive full and free competition in accordance with ASPR policy, with only remote situations justifying direct negotiation. (See "Neogitation" this chapter.)

The Corps, acting for the using activity, insures that the facility is provided in accordance with the approved construction documents, coordinates any modifications necessary during construction, recommends partial payments to the contractor, and determines final acceptance.

The contractual relationship of the parties to traditional construction in private industry is generally described as being linear in nature. The architect's contract with the owner provides primary responsibility in administering the construction contracts, and representation of the owner in nearly all of the construction process. The manufacturers of building components are solicited by the prospective contractors during the bidding stage and have very little participation, if any, in the planning stage during which design and scheduling decisions are made. Subcontractors generally have no contractual relation with the owner, as the prime contractor is most often established as having sole responsibility for the work. Thus Government procurement policies merely require the prime contractor to submit the names of his subcontractors to the contracting officer and demonstrate that all labor requirements are being met. The prime contractor is further required to perform a significant part of the work with his own forces to assure adequate interest in the project.

Traditional contractual relationships and procurement procedures can be utilized in an industrialized application with the design function of the architect/engineer directed towards the development of a collection of subsystems designed for a particular project. These subsystems would be usable for similar projects or building types and would therefore have the advantage of multiple utilization, one of the techniques which is prerequisite to an industrialized process. The project designed would be a closed system due to subsystems being designed to interface with each other for the particular project. However, once developed, their application to similar projects would be easily accomplished.

Upon design of the subsystems comprising the building project, bidding is then accomplished in a traditional manner with award being made to the low responsible bidder. The "bidder" may not, however, be the traditional general contractor we know of today. He may be the erector, but alternatively, he may just as well be the manufacturer of a major subsystem. In either case, he has a sufficient part in the work to satisfy the regulations pertaining to prime contractors and he still has the responsibility for the performance of all work.

The Construction Manager

Within the last several years, a significant change has been taking place in the building industry with management of construction projects being assumed by firms bearing the title, Construction Manager. The impact of this shift in responsibility from architects, engineers, and construction firms is revealed by the proportion of construction that is proceeding under management other than the traditional form in many of the active construction areas. A recent survey in Toronto, one of the most active construction areas in North America, revealed that over 90 percent of construction utilized new management processes. Professional design organizations are recognizing this trend and are taking steps to inform and educate their members. For example, the American Institute of Architects will soon release a report outlining the latest developments in total management organization which creates a team involved simultaneously in all decisions required for a project from the planning stage through the execution of construction. This team is generally comprised of the owner, the architect, and the construction manager. The Associated General Contractors of America is taking similar steps with its members in an effort to provide an impetus for the General Contractor to assume this role.

Several governmental agencies have initiated programs utilizing construction management on their projects. The General Services Administration plans to utilize a limited Construction Manager under the supervision of a Project Manager on projects larger than \$5 million with their services being obtained through a negotiated professional service contract. Their duties will correspond generally to those normally performed by a general contractor and additionally include other administrative service:

TRADITIONAL PROCESS

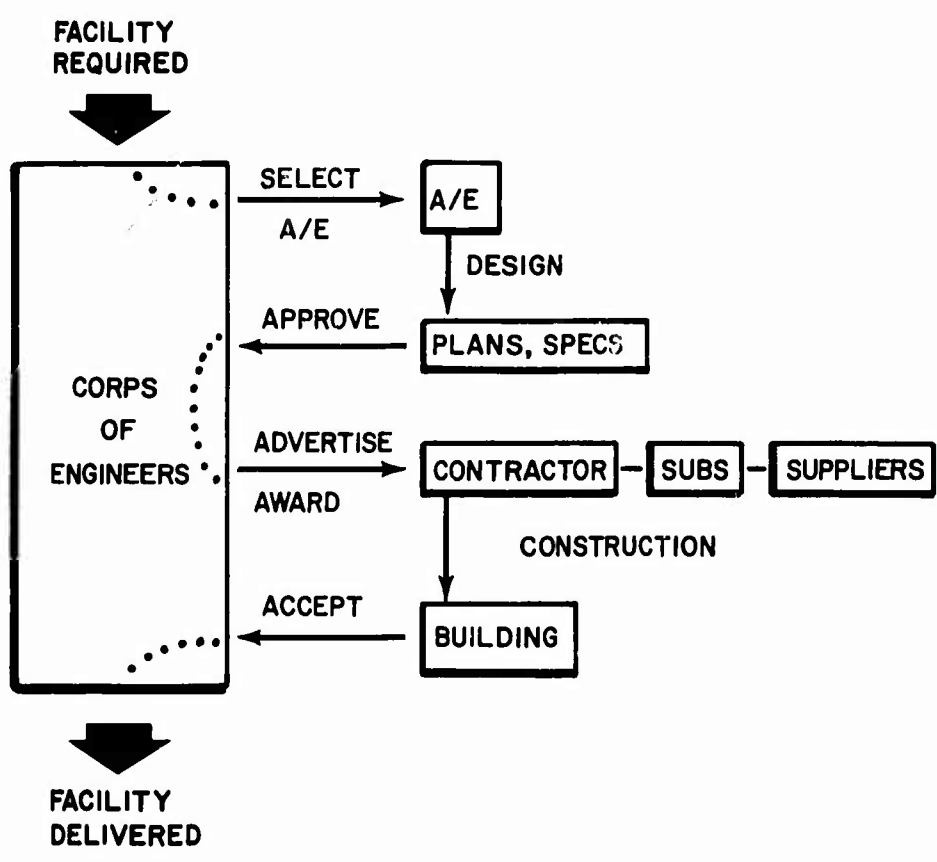


FIGURE 4

cost expertise to the architect; review of design studies
management of procurement effort;
construction supervision
maintenance of CPM schedule
approval of subcontractor pay estimates
final inspection

The GSA has taken these steps to hopefully enable the government to save time and money. They look for the team of the architect, construction manager, and project manager to accomplish this.

The construction manager fills a new role in the construction industry. Involved in the project from its inception, he brings to the team the contractor's point of view, brings to the contractor the architect's point of view, and helps the owner by developing and coordinating necessary economic balances between the architect and contractor. There appears to be a tendency for more participation by contractors in the design-economy process and for more owners to seek their buildings through a joint venture between designer and builder. The difference in owner attitudes results from the construction managers being able to convince owners that appreciable amounts of time and money can be saved through the application of industrial management techniques and continual cooperation between the members of the building team. The actual source of these managers comes from several segments of industry. Both architects and construction contractors place themselves in the position of assuming the expanded managerial role due to their historical involvement in this area. However, still another group, management consultants, is vying for this function.

METHODS OF PROCUREMENT

As Figure 5 illustrates, numerous methods of procurement are available to both industry and Government.

Negotiation (Bilateral Price Determination)

Negotiation of architect/engineer service contracts is provided for in the Procurement Regulations, obtaining its justification by virtue of the difficulty in determining the exact amount of the work to be performed and the professional ethics of architects which preclude a competitive selection of their services.

However, for the procurement of construction, authority to negotiate is limited to a very specific range of conditions that recognize that full and free competition cannot be maintained when one or more of these conditions exist. Several of these conditions relate to urgency of facility need, i.e., national emergency, and public exigency. Other conditions favorable to negotiation occur when it becomes impractical to formally advertise and can result from: (1) a supplier being a sole source of supply, (2) patent rights of a product do not allow others to provide a desired product, (3) no response has been received from a solicitation of bids, (4) the exact nature or amount of the work is unknown, and (5) it is impossible to draft adequate specifications.

These limited conditions for negotiation normally preclude realization of construction procurement by other than formal advertising and competitive bidding. Although one-third of the surveyed firms prefer competitive bidding, there are movements within the industry to both change the bidding system, and move to other methods, negotiation being most enthusiastically pursued. This is reflected by the third of the firms in the survey that evidenced a preference for negotiated procurement (see Fig. 6).

It is generally accepted by the industry, however, that except for unusual project requirements such as expediency, negotiation in the public sector is not appropriate. Negotiation can have the advantages of a somewhat less adversarial relationship between the contracting parties, contractor input at the design stage, and more control over the selection of a responsible contractor; however, if the selection of the contractor for a project is not competitively based, the public may be suspicious of the exertion of unfair influence in obtaining the work. Further, the number of firms considered becomes smaller with new, inexperienced, possibly very capable firms not receiving consideration.

Two Step Formal Advertising

One method available under existing procurement regulations that addresses the requirement for flexibility is the use of performance type specifications and two-step formal advertising. This method is designed to utilize the benefits of formal advertising (competition) where specifications are not sufficiently detailed to use conventional formal advertising.

Simply, it involves in the initial step, an evaluation of technical proposals that were prepared based on performance type specifications. At the conclusion of this stage, a list of acceptable proposals is acquired, their acceptability contingent upon specification compliance, without regard to pricing.

A second step follows the traditional process of conventional bidding, bid evaluation, and award, except that the advertisement for bids is limited to the list of acceptable proposals determined in step one.

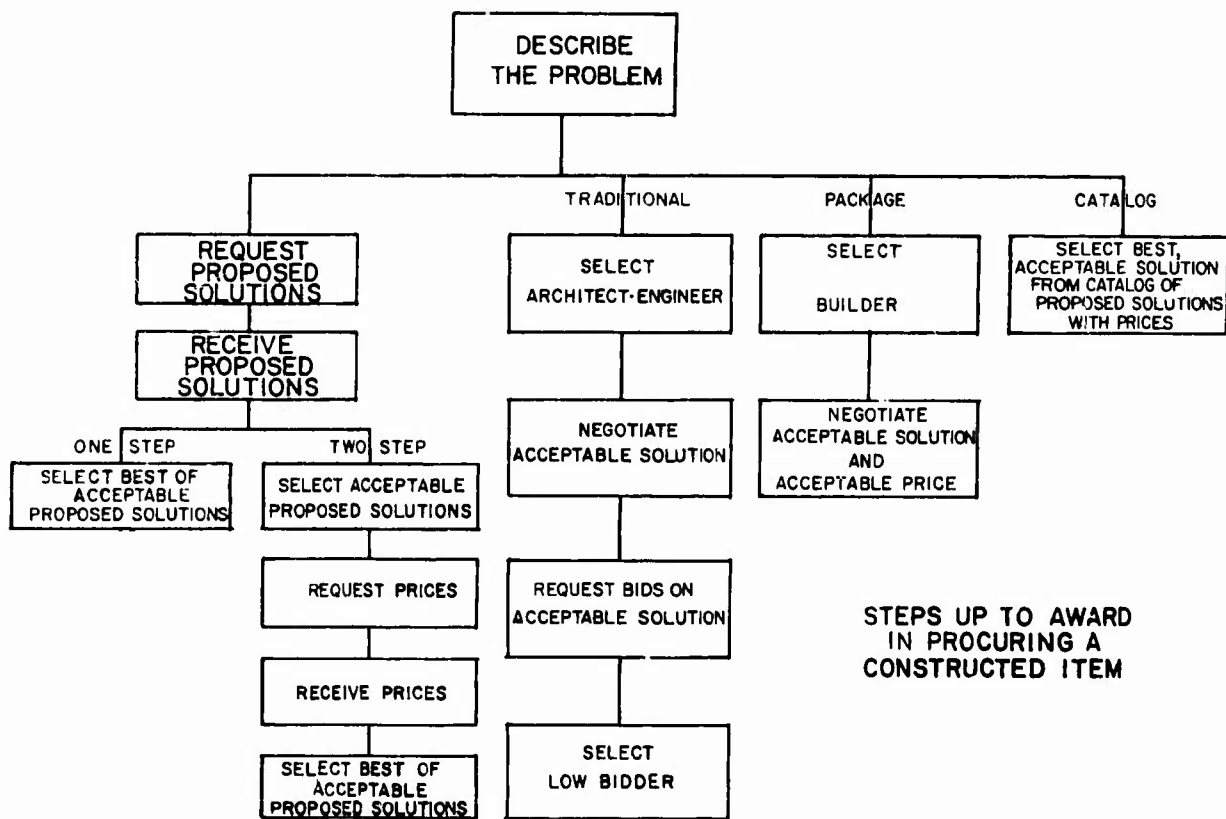


FIGURE 5

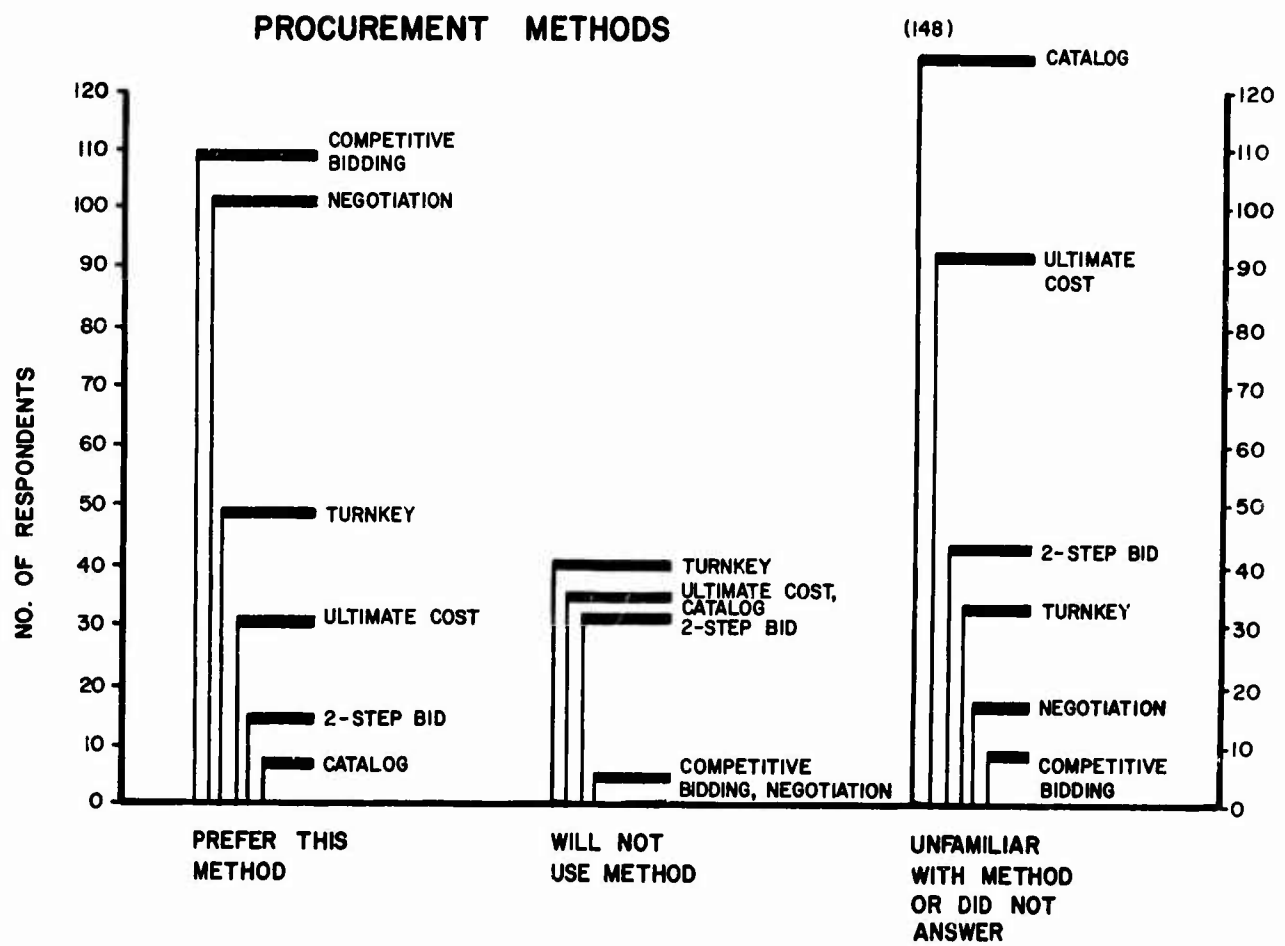


FIGURE 6

Prerequisites to the use of this method are several conditions that can be satisfied by the industrialized building industry and can be satisfied by the procuring agency: (1) the diversity of acceptable products precludes definitive specifications, (2) multiple sources are available (see "Design Compatible," this report), (3) sufficient time is available for use of the method, and (4) a firm fixed price contract can be utilized. Only one condition requires further action, that being the development of performance requirements (specifications). Nearly all of the current construction is procured via definitive specifications, with much of the criteria in DOD 4270.1M, "Construction Criteria Manual" being in similar language. Minor modifications in these standards suggested in Appendix A could provide a vehicle for the subsequent development of performance specifications. Figure 7 demonstrates the significant use of performance requirements by A/E firms to describe industrialized building systems.

The use of 2-step formal advertising is not without precedence, as it has been successfully used by other public agencies as well as the U. S. Government for the procurement of construction. However, experience with this method to date has revealed that because of the high degree of design development required in the proposal stage (which also includes pricing considerations by the proposer although he is not required to furnish this in the first step), many firms have been investing thousands of dollars in their proposals for each project, only to be excluded by the price-based selection. It should be noted that only 42 percent of the firms in the survey indicated they were willing to use this method, 6 percent preferred the method and 11 percent would not even bid this way, notably some of the complete systems firms. The gamble the construction industry takes every day in preparing bids is not new, except that by this method, a much greater investment is made.

One-Step Negotiation

This method follows the 2-step procedure as described herein to the point at which the submission of the prospective bidders are evaluated according to qualitative criteria issued with the Request for Technical Proposal. However, instead of a selected list of acceptable proposals being created for a second step of competitive bidding, a single acceptable system is selected with either the price being included in the proposal or the price for manufacture and erection is determined bilaterally or by negotiation. Determination of price by negotiation is, as was described earlier, generally in conflict with ASPR policy of pricing competition. Additionally, the selection of a single proposal from possibly many acceptable proposals can create dissatisfaction within the industry because of the possibility of variable and inconsistent judgments on the part of the selection agency. The process can be vulnerable to claims of biased or unfair consideration of particular proposals and is most appropriate for a pilot or experimental project where it is clearly shown to the industry that it would not be a continuing procedure.

Package

This non-competitive form of procurement typically involves negotiation with a selected builder who possesses design, construction and service capability. Usually, a selected builder submits a package proposal often including the purchase of land, that has a guaranteed cost, time and quality of construction. 37 percent of the firms indicated preference for this method, however, due to a lack of competition, it is not a compatible method under present procurement regulations.

Catalog

Similar in nature to procurement methods utilized by the GSA in the purchase of supplies and services, this technique makes available to an A/E a 'catalog' of pre-accepted or certified open or closed subsystems for his use in designing a specific project. This catalog of acceptable subsystems may be obtained by several methods: (1) a collection of integrated subsystems can be designed through traditional A/E services followed by a competitive bidding procedure to establish a "list price" for each subsystem as with the School Construction Systems Development (SCSD) or, (2) components and subsystems that have been developed independently by industry can be evaluated and certified. By the former, the quantity of the subsystems needed would have to be determined in advance through aggregation of projects, to establish sufficient volume to justify production.

For subsequent procurements, by having established component prices prior to the selection of materials and constructions, this method removes many of the unknown factors in meeting project budgets. It does place a high responsibility on industry, though, to develop the components that are needed as well as having their development fall within the framework of dimensional coordination. An information retrieval system or usable standard catalog form of presenting the data on their components to the design profession is also necessary.

Certification of existing systems may be accomplished through testing programs such as model building code organizations, state programs for laboratory evaluation of components, FHA approval techniques, or certification by independent testing laboratories who have conducted the testing in accordance with procedures established by the Army. Additionally, research and testing facilities exist in the Armed services which have the capability for providing this service: The U. S. Army Construction Engineering Research Laboratory, and the U. S. Navy Naval Civil Engineering Laboratory.

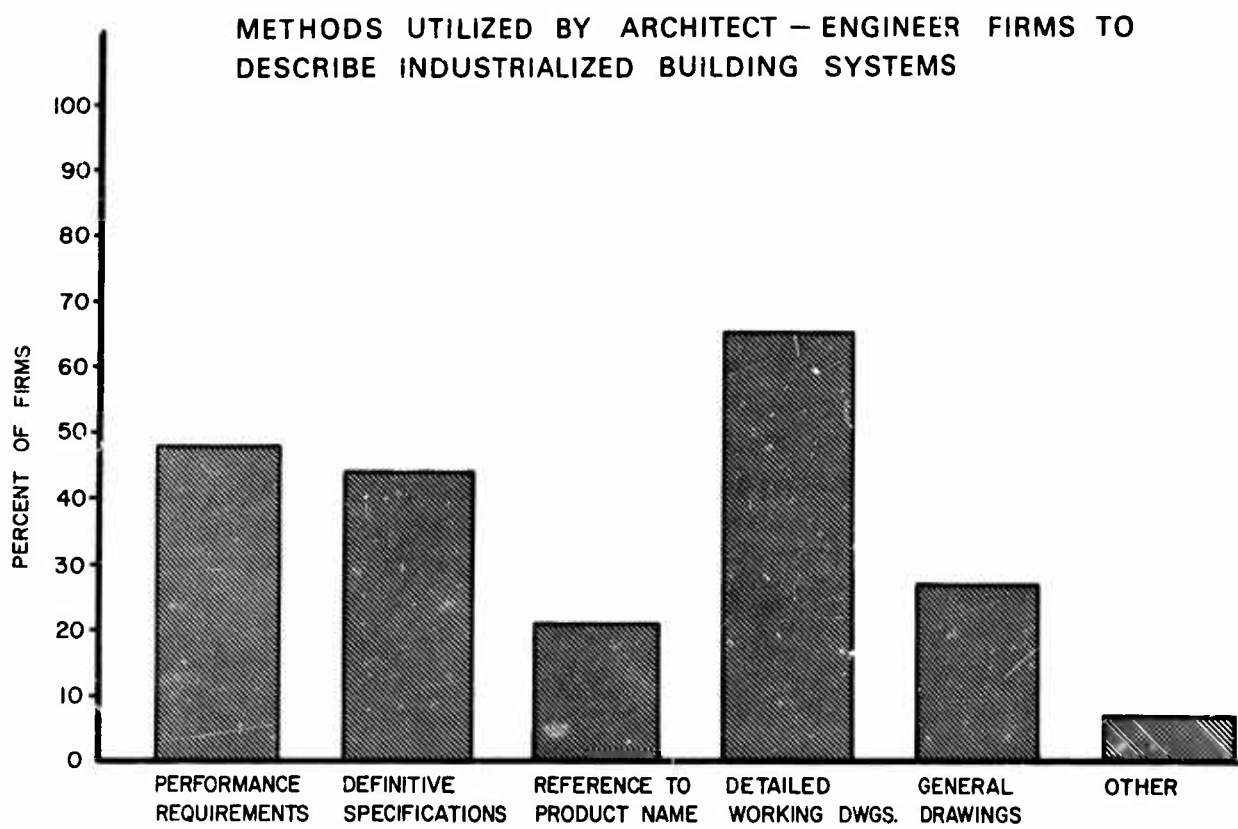


FIGURE 7

How does this method differ from the present process of A/E's selecting products and materials from the manufacturer data such as Sweet's File? It doesn't in concept, but it does in actual practice as there are certain characteristics such a catalog of components must possess. It must:

1. present data in a uniform format.
2. contain only components that possess dimensional compatibility with others affected by its use (interface).
3. illustrate all components with drawings and details in a consistent manner.
4. be kept current to show only those components available on the market.

Hopefully, such an amassing of product and component data will lead to a modification of a portion of the design process in which materials and constructions are selected. Presently a material or construction is selected based on a reasonably satisfactory performance in the past and a moderate cost; however, the achievement of an optimum design is too often the result of luck. The A/E can hardly be criticized for this situation as the mountain of product information available to him in a more or less complete form makes sorting for optimum cost, life cycle cost, dimension, and performance just to mention a few, a monumental if not impossible task. Component catalogues display all available options satisfying initial design requirements and hence permit final selection from a more manageable array of possible solutions.

Another form of catalog procurement—an extension of the component catalog—puts at the disposal of the using activity a selection of complete buildings or solutions that have established prices by previous competitive bidding or by the company for market sales. The pre-engineered or metal building, tailored to a specialized end-use or market, and with a need for repetitive sales of a specific design would be an obvious example of this method. Another example of this type of catalog is the widely used "BUSH" contract.

Describing the Building Requirements for Procurement

In order to comply with policy established by the Armed Services Procurement Regulations which provides, "Plans, drawings, specifications or purchase descriptions for procurement shall state only the actual minimum needs of the Government and describe the supplies and services in a manner which will encourage maximum competition and eliminate insofar as possible, any restrictive features which might limit acceptable offers to one suppliers product, or the products of a relatively few suppliers" (ASPR 1-1201.a), the procurement of industrialized buildings by the Army needs to be flexible enough to allow for methods other than the traditional one involving an A/E preparing plans and specs, advertisement for bids, and award to the low bidder. This flexibility is required by the nature of the product and the producer. So diverse are the products presented by the manufacturers of the available open and closed systems and subsystems that the traditional definitive specification of materials is inappropriate in order to gain the widest selection of products. Continued use of 1 step and 2 step procurement would therefore seem desirable.

To broaden competition, procurement methods should provide a vehicle for stating building requirements that will allow both the industrialized building and the conventionally constructed building to be utilized. U. S. Army design policies for military construction tend to inhibit innovation in construction as is illustrated by statements from ER 1110 345-100: "Unusual or new materials or methods of construction will be avoided and will not be used unless approved by division engineers." . . . "Methods of construction previously untried for military construction will be incorporated in the design only when evidence shows conclusively that such use is in the interest of the Government from the standpoint of economy and quality of construction. Unproved methods and materials will not be used." The former requires conclusive evidence on the part of the manufacturers in the form of lab tests (and therefore requiring standards to which the product can be compared) and proof of satisfactory installation under similar conditions as the project. The latter, by referring to methods being "incorporated into the design" implies that the decision must be made ahead of time to use a specific method or material. This is in conflict with another policy, stating, "Generally, proprietary materials, systems and processes" (Closed or named systems and subsystems) "will not be employed to the exclusion of other materials, systems and processes or in ways that might be restrictive" . . . (to conventional construction or closed industrialized systems). This is not to say that the Government building program should serve as a proving ground for industry.

This dilemma is compounded by the difficulty of stating building requirements that would simultaneously allow conventional and industrialized construction techniques to be employed. Several options available which would satisfy the diversity needed, but include inherent disadvantages are:

1. performance specifications and general design drawings.
2. definitive specifications and drawings (for conventional construction) with option for alternate proposals, at the bidding stage (not allowed by ER 1110-345-100 (10.): qualified bids).
3. Same as No. 2 except utilize the provision of the value engineering incentive clause after the award is made on the basis of conventional construction. (The contractor has no guarantee his industrialized proposal will be accepted.)
4. definitive specifications and drawings and performance requirements included in the same document.

The first option provides the most consistent degree of fairness to both sources, however it does cause the contractor for conventional construction to acquire design capability. It also places the responsibility of developing the performance requirements on the Corps of Engineers, who, with the assistance of systems designers and manufacturers would create such requirements in a form conducive to the development of technical proposals. For purposes of procurement, these requirements are written in the form of performance specifications in which the desired characteristics of a product's or system's performance are stated without reference to specific means of achieving the results.

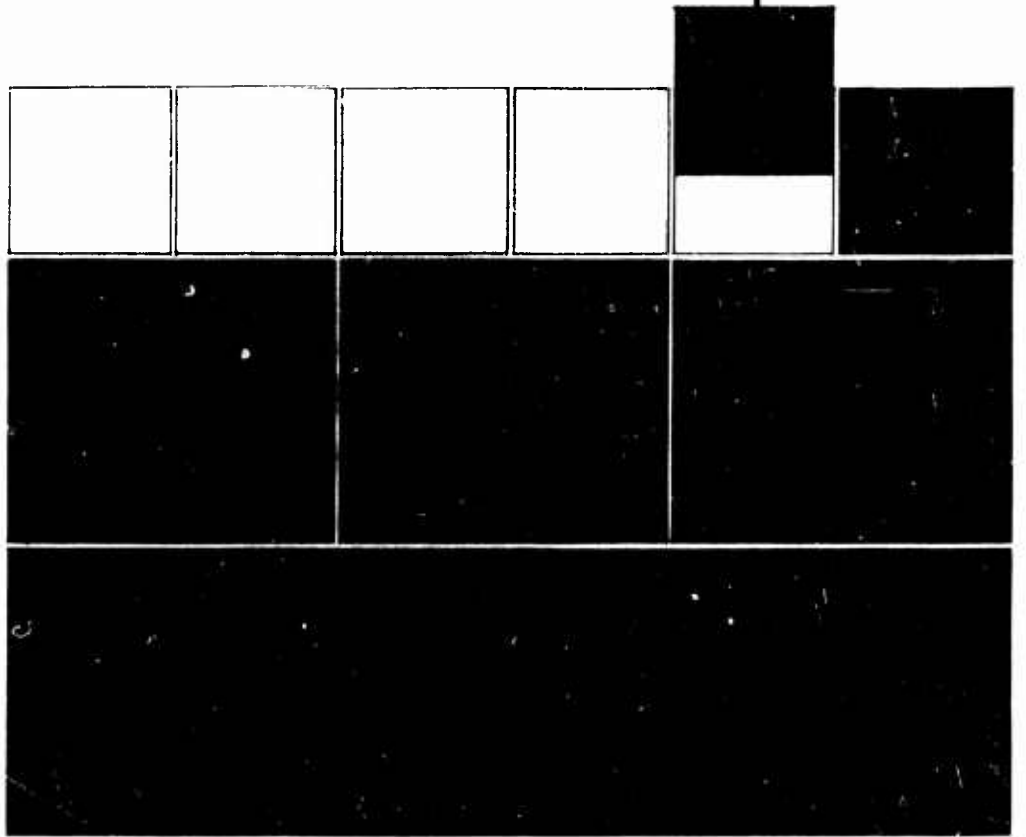
On the other hand, options 2, 3 and 4, place the industrialized builder at a disadvantage by virtue of his needing to provide design service in order to propose an equivalent building to that for which conventional construction documents have already been provided.

PROCUREMENT COMPATIBILITY OF THE INDUSTRY

Procurement compatibility of the surveyed industrialized building industry firms was determined by identifying those firms that satisfied the following two criteria: (1) the firm will sell its product directly to the owner (client) and (2) the firm's procurement methods are readily adaptable to present government procurement regulations. The methods of procurement for which they indicated sole use, preference for, use of, willingness to use, unwillingness to use, or unfamiliarity with are as follows:

| | |
|----------------------------------------------------|----------------|
| Unilateral price determination—competitive bidding | (compatible) |
| Bilateral price determination—Negotiation | (uncompatible) |
| Ultimate Cost—competitive, includes future cost | (compatible) |
| Two Step Bidding—competitive bidding | (compatible) |
| Turnkey—package building | (uncompatible) |
| Catalog—certified component | (uncompatible) |
| 1-step—evaluated bids | (compatible) |

Table 5, Appendix B (FOUO) includes the list of firms possessing only procurement compatibility, Table 2, Appendix B (FOUO), the firms both procurement and design compatible, and Table 3, the firms both procurement and production compatible.



production compatability
6

CHAPTER 6 – PRODUCTION COMPATIBILITY

INTRODUCTION

Although it has been shown previously that there is a climate in the U. S. resembling that of the past where a need existed for a large volume of building consistent with a high degree of economy, the industrialized building industry in the U. S. today is in the early stages of maturity.

The incipient character of the industrialized building industry is perhaps best portrayed in Figure 8 a cumulative frequency distribution of firm experience with industrialized building.

As the diagram illustrates, only 41 percent of the surveyed firms indicated first production commencing prior to 1963 while 1 out of 3 respondents initiated production subsequent to 1968.

The median age of all manufacturer-suppliers was 6 years, of which 88.7 percent claimed to be in full production.

As Figure 9 illustrates, the industry is relatively small in relation to the 40 billion dollar a year conventional construction business. 30.7 percent of the respondents exhibited gross annual earnings below 1 million dollars, while 63 percent of the firms operated businesses with market volumes below 5 million dollars annually.

43 percent of the firms—all wood systems—claimed to be able to transport their product beyond 500 miles from factory.

DEFINITION

Determination of the production compatibility of the industrialized building involved comparison of Army CONUS building projects with the characteristics the industrialized builder specified or possessed that allowed him to complete with the conventional builder.

An important characteristic of the industrialized building industry for which a counterpart in conventional construction is not seen is marketing and distribution. The criticality of marketing to industrialized building is due to its dependency on a sufficiently large and sustained market in order to justify a very high expense in setting up production facilities and tailoring them to particular projects. A minimum of design modifications is an obvious objective. The existence of a sufficient market will be a highly critical factor in determining the production compatibility of industrialized systems with Army CONUS building programs. This chapter will then address the following questions: (a) can the industry serve the needs of the Army, (b) can the Army alone support industrialized building or will all services requirements need to be aggregated, and (c) what is the likelihood of industrialized building succeeding in its competition with conventional construction.

INDUSTRY CAPABILITY

A characteristic of the industrialized process is a sustained operation of the plant and machinery or long production runs in order to realize a return on the large investment. This is accomplished by a simultaneous development of product design, marketing plans, production stability, and customer acceptance. Quite naturally, the customer wants any new material or system to be proven before he uses it; contrarily, the manufacturer must have a sufficient volume to justify research and development. When asked the specific question as to the required dollar market volume over a 2 year period to justify the expenditure of research and development funds for the design and bidding of systems solely applicable to U. S. Army facilities, approximately one-half of the firms required a \$1,000,000 market or less, one third required a \$2-3,000,000 market and the remainder required a \$4-6,000,000 market. This is clearly indicative of the required size of a project for industrialized solution (Fig10).

Another measure of the capability of the industry is the minimum output required by a firm for a particular project to justify a production run. In the survey, 4 categories of output were listed with dollar volume receiving the greatest response. 65 percent of those responding indicated a production run was justified with less than \$500,000 of output, 20 percent stated between \$500,000 and \$1,000,000, with the remainder primarily in the \$2-3,000,000 range. The character of the products must also be considered along with these figures due to the relative expense of certain manufacturing processes. The distribution of predominant generic materials comprising the surveyed systems is as follows:

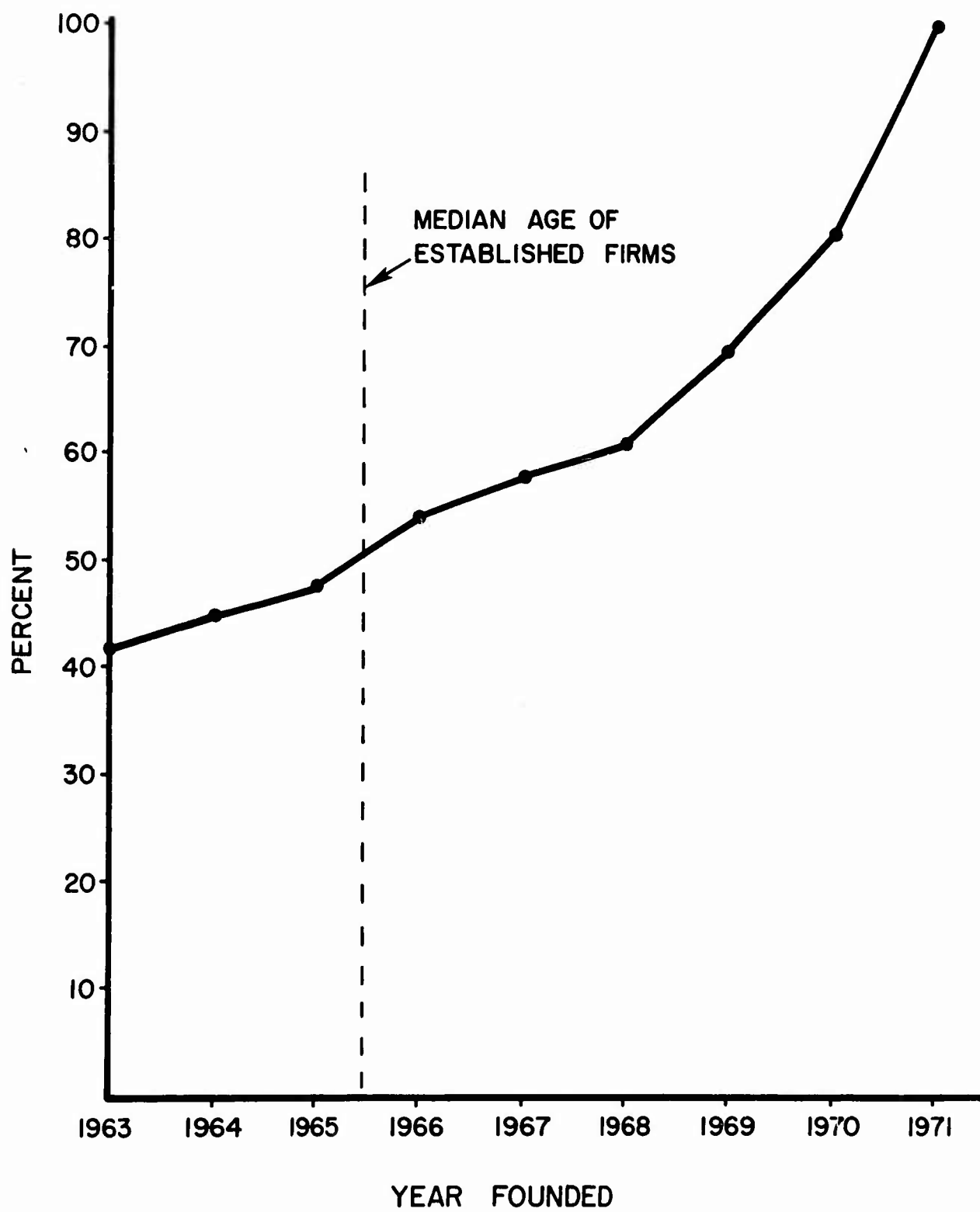


FIGURE 8

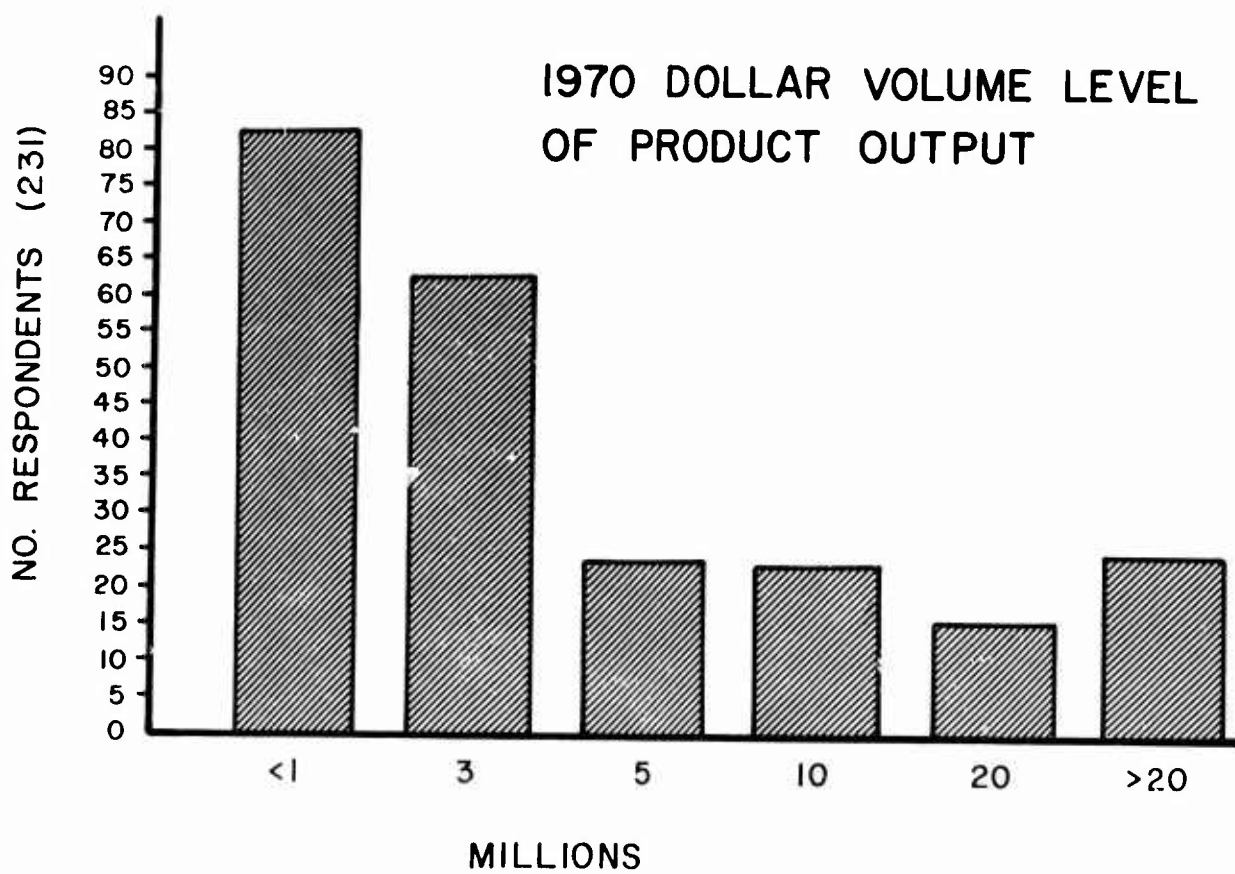
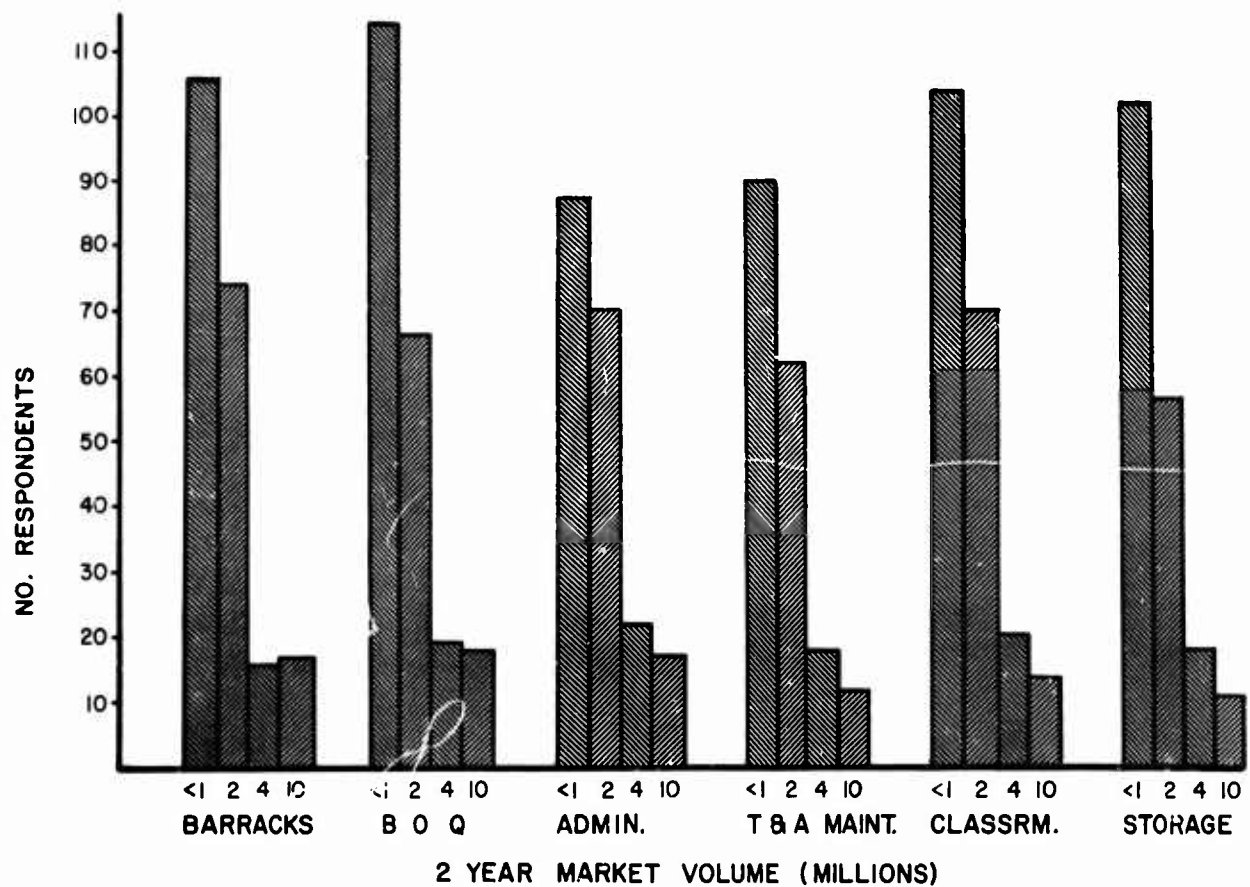


FIGURE 9



**DOLLAR MARKET VOLUME REQUIRED OVER 2 YEAR
PERIOD TO JUSTIFY R & D FUNDS**

FIGURE 10

| | |
|---------------------------|-----|
| Masonry | 2% |
| Wood | 50% |
| Steel | 21% |
| Precast Concrete | 17% |
| Cast in place concrete | 1% |
| Others | 8% |

The predominance of wood systems or processes tends to make the overall output requirements somewhat lower than other systems would demand.

Effects of Product Alteration

The question of a justifiable production run for a specific U. S. Army project is also related to the required degree of alteration to the firm's standard product to suit the Army's need. Investigation of Figure 11 will show that generally, alteration of the product's dimension or the building configuration can be easily accommodated, however, a significant number of products do possess some difficulty in being altered. Alteration of material properties seems to cause the most difficulty, making changes of these properties (to conform to Army criteria not standard in the industry) an economical disadvantage.

The effect of product alteration on one of the professed advantages of industrialized building, that of short construction time, was also investigated. Figure 12 illustrates that significantly altering the standard product dimensions increases the modal production time by approximately 4 weeks while significantly altering the material properties adds still another 4 weeks to production time.

NEEDS OF THE ARMY

Recapitulation

A discussion of the Army's upcoming building projects has preceded this chapter and revealed, to briefly summarize, that the greatest concentration of projects in the 5-year Military Building Program exists within the 6 building types named: Enlisted Men's Barracks, Bachelor Officer Quarters, Installation Storage Facilities, Classroom-type Training Facilities, Administrative Buildings and Tank and Automotive Repair Facilities.

Geographical Distribution of Need

The total programmed construction is significant, of course, but is not the prime consideration in the analysis of an ample market. Because of the effect of shipping distances on a product's distribution, and the required availability of a complete array of subsystems for a building at a particular location, it is necessary to compare the value and characteristics of specific projects at specific bases with available potential firms and their capability to provide the required products. To accomplish this, projects in each of the 6 building types for all 3 services were identified and accumulated into 82 zones of 50 mile radius. These are shown on Figure 13.

Each zone contains at least one Armed Services installation with planned construction of a facility in one or more of the 6 major building types in FY 73-77. Wherever possible an Army installation was made the center of the zone (the 50 mile radius is approximate as a few installations as far as 70 miles from a zone center are considered part of the zone). In 37 zones no Army installations exist which plan construction in 1 of the 6 major types in FY 73-77. Table 4 lists the installations found within each zone.

The location of each of the manufacturing plants of the 275 respondents to the survey (Fig. 14) was then superimposed on the zone map with all zones falling within the manufacturers stated economical shipping radius identified as capable of being served by that manufacturer.

Figures 1-7, Appendix A (FOUO) show the dollar value 5 year planned construction for each of the 6 types and their total for the Army as of September 1970. Each circle is centered about one of the zone centers. The size of the circle reflects the magnitude of the dollar value in accordance with the legend for the figure and has no meaning in a geographical distance sense. These figures give overviews of the geographical dispersion of future dollar expenditures and indicate regions where large building investments are planned. The tabular presentation of this data is given in Table 5 Appendix A (FOUO) and lists the dollar values for each zone.

Figures 8-14, Appendix A (FOUO) portray the dollar value 5 year planned construction for the Armed Services for each of the 6 selected types and for the total of these 6 types for each of the 82 geographical zones.

Table 6 Appendix A (FOUO) presents in tabular form this data for each geographical zone.

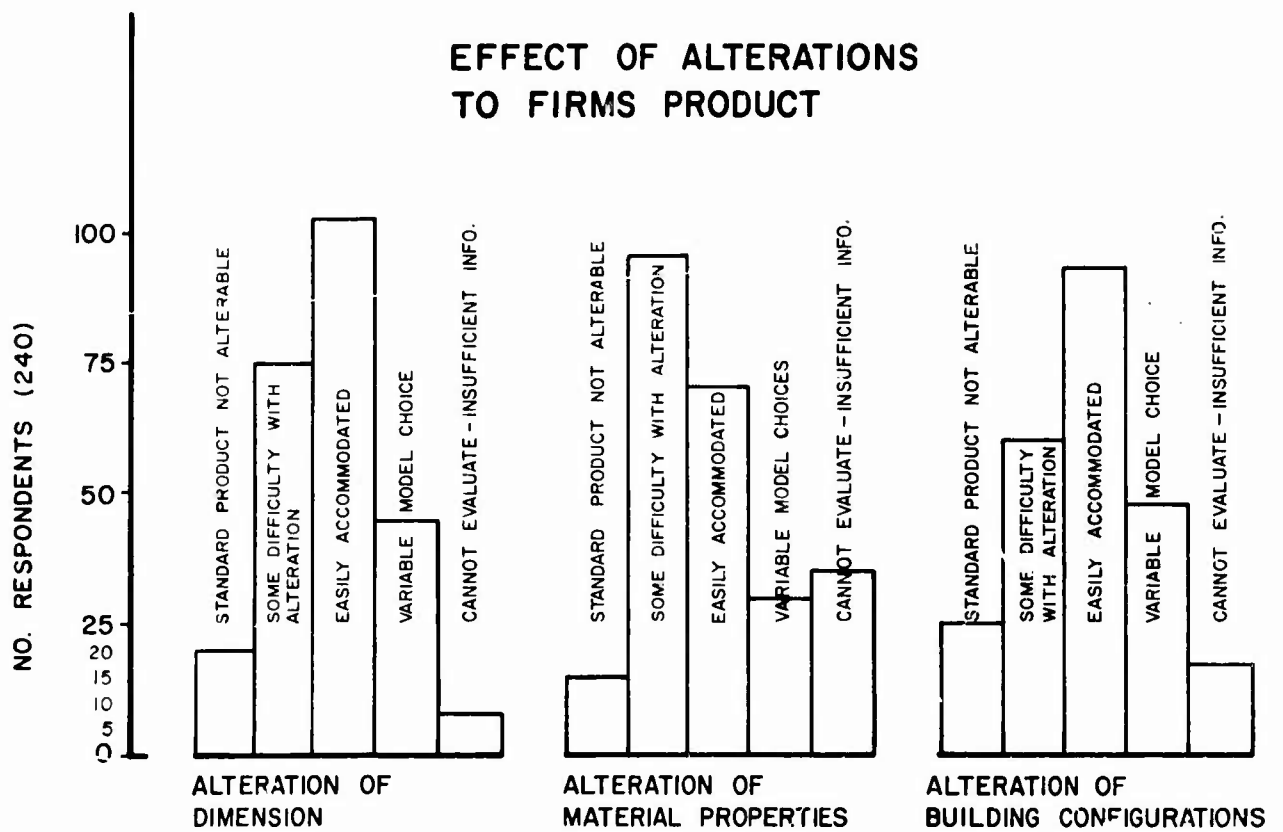
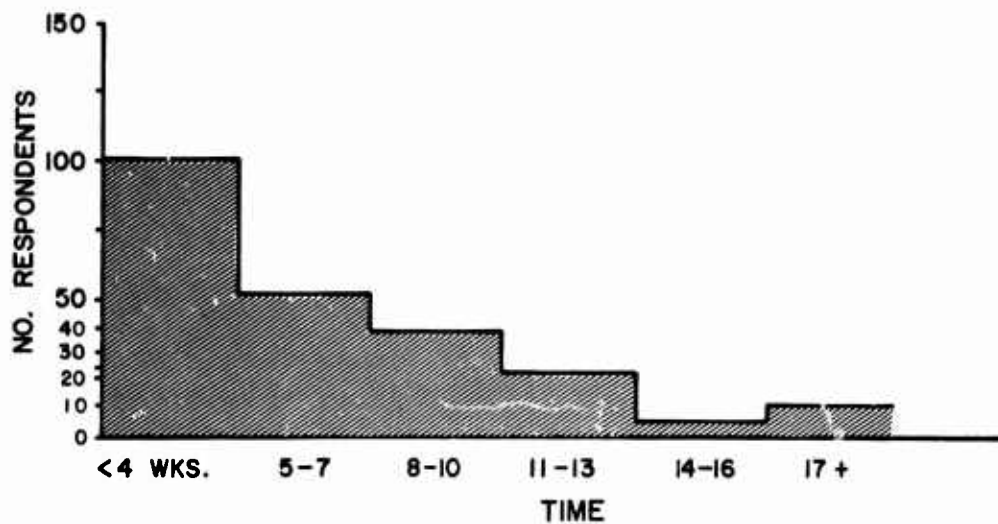
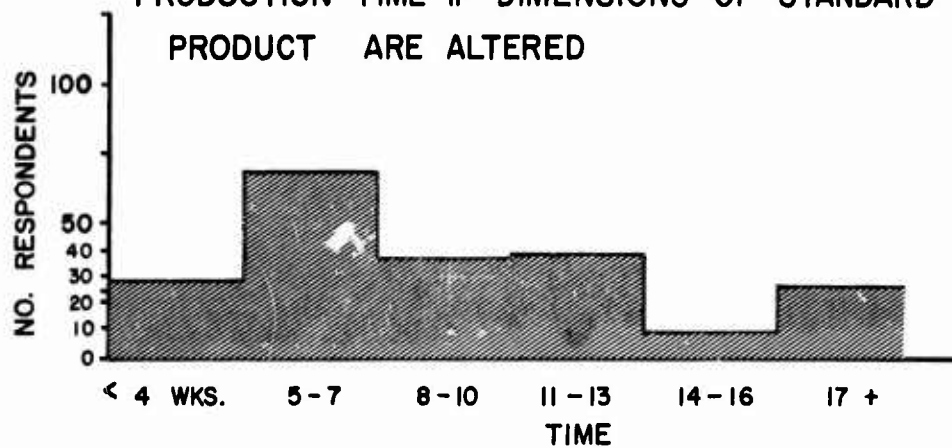


FIGURE 11

STANDARD PRODUCT PRODUCTION TIME



PRODUCTION TIME IF DIMENSIONS OF STANDARD PRODUCT ARE ALTERED



PRODUCTION TIME IF MATERIAL PROPERTIES OF STANDARD PRODUCT ALTERED

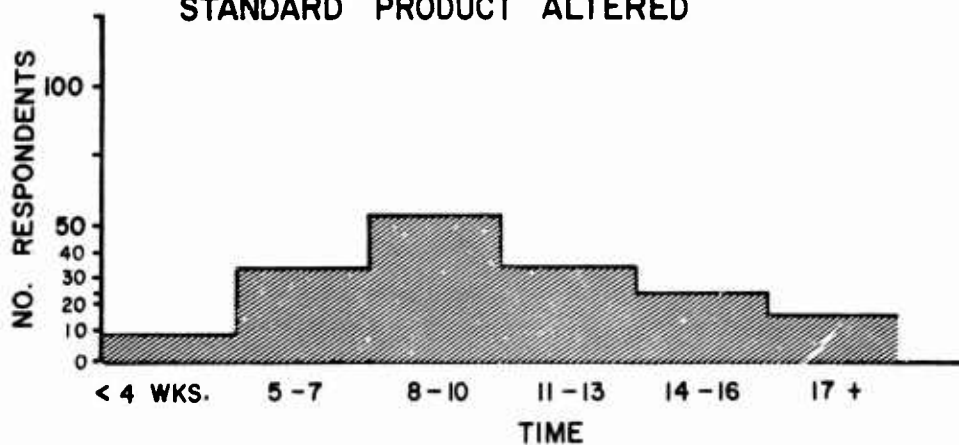
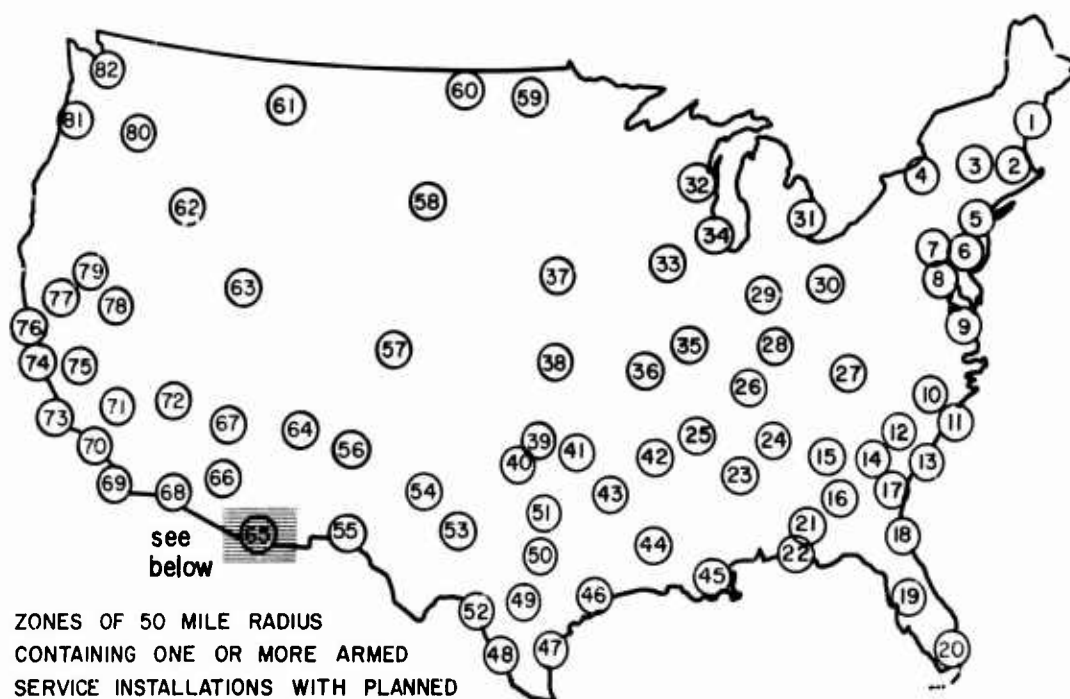


FIGURE 12



ZONES OF 50 MILE RADIUS
CONTAINING ONE OR MORE ARMED
SERVICE INSTALLATIONS WITH PLANNED
CONSTRUCTION IN ONE OF SIX BUILDING
TYPES.

FY 73-77

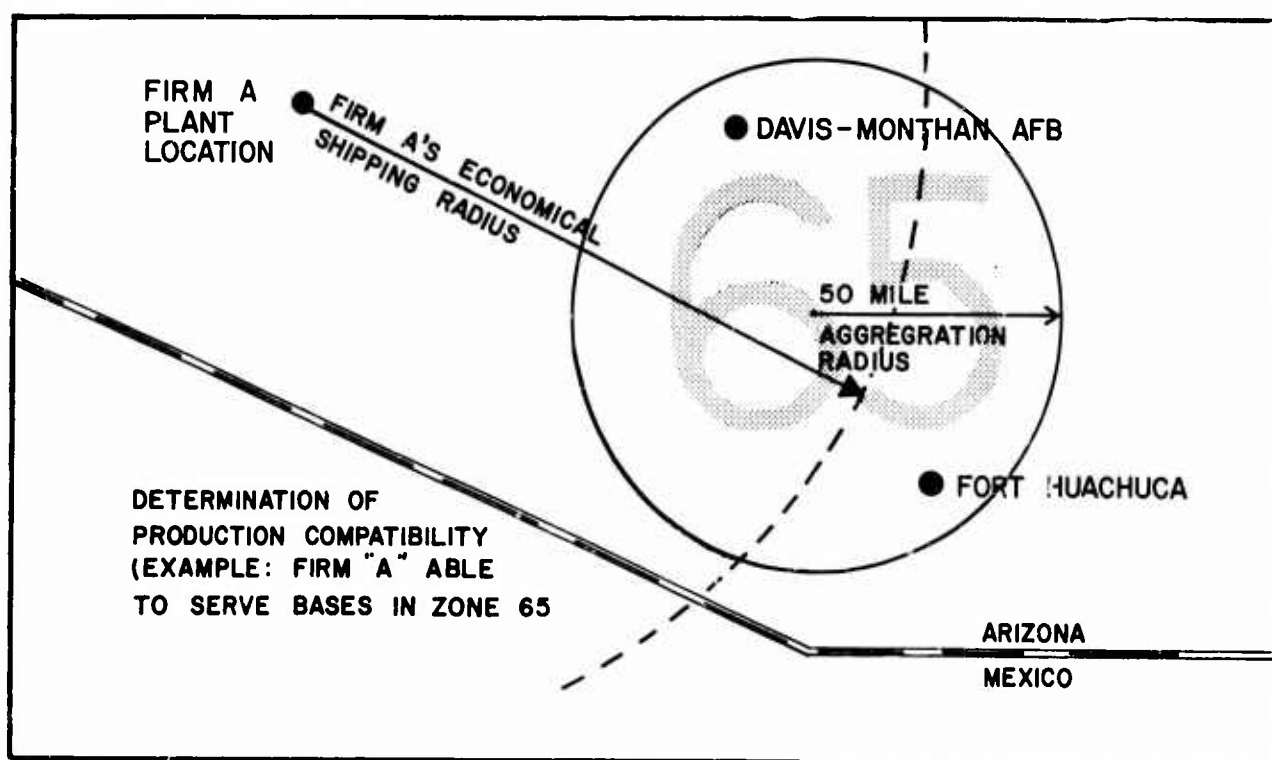


FIGURE 13

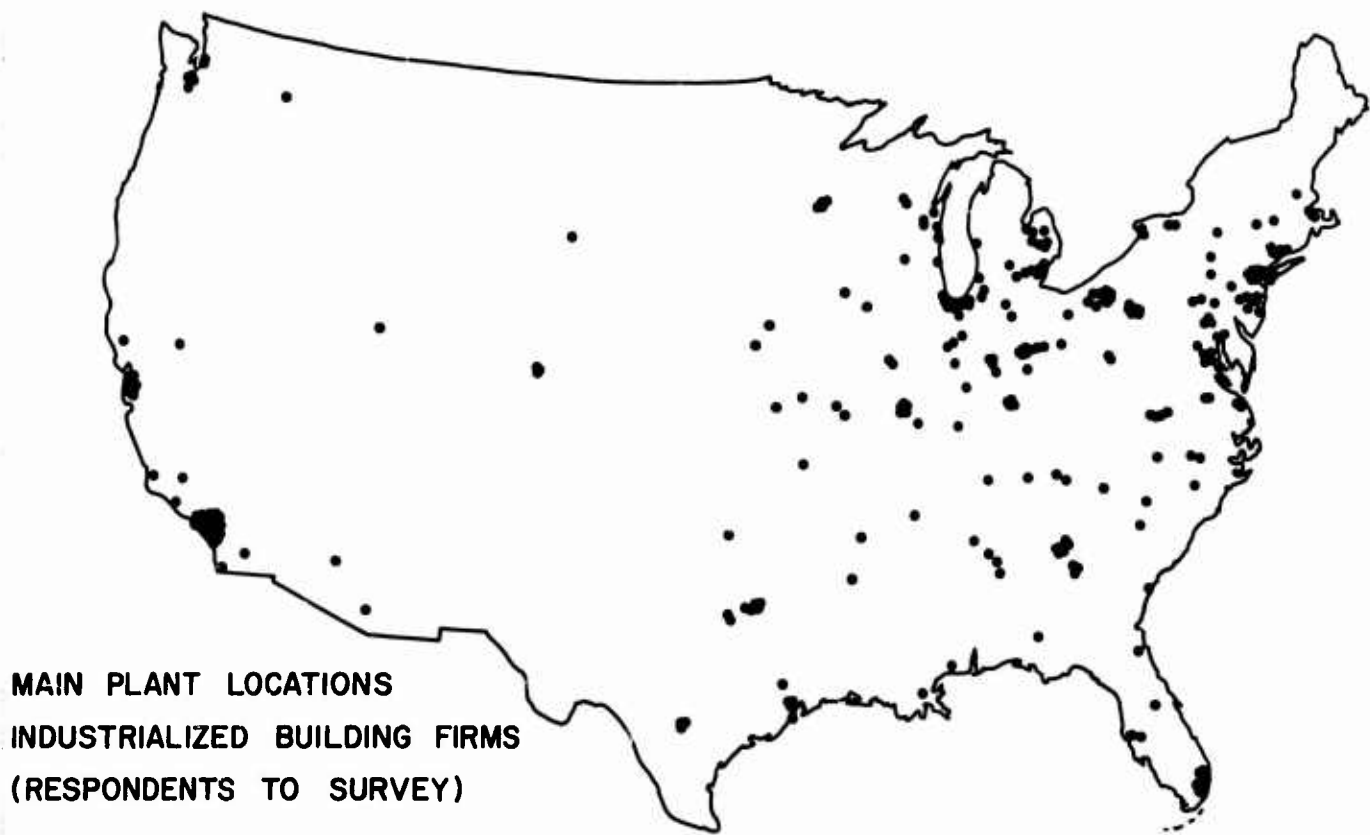


FIGURE 14

Table 4

**List of Installations* in Each Geographical Zone
(5-year Military Building Program within 6 Building Types Only)**

| ZONE | INSTALLATIONS |
|------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| 1 | <u>*Portland, Maine</u> : Brunswick NAS, Portsmouth NAS |
| 2 | <u>Worcester, Massachusetts</u> : Fort Devens, Natick Lab, Boston NAS, Chelsea NH, Springfield MCN Quonset |
| 3 | <u>Watervliet Ars., New York</u> |
| 4 | <u>Seneca AD, New York</u> : Syracuse NTC |
| 5 | <u>Picatinny Ars., New Jersey</u> : Bayonne MOT, Stamford NAS, Ft. Monmouth, Tobyhanna AD, Brooklyn MOT, St. Albans NAS, Ft. Hamilton, Allentown MCRTC |
| 6 | <u>Wilmington, Delaware</u> : Lakehurst NAS, Johnsville NAS, Willow Grove NAS, Dover AFB, Bainbridge NTC, McGuire AFB, Fort Dix, Camden MCA Philadelphia NAS, Ft. Miles |
| 7 | <u>Carlisle Barracks, Pennsylvania</u> : New Cumberland AD, Letterkenny AD, Ft. Richie |
| 8 | <u>Washington, D.C.</u> : Edgewood Ars., Ft. Meade, Vint Hill Farms Sta., Ft. Belvoir, Ft. Myer, Ft. McNair, W. Reed AH, Arlington Hall Sta., Bethesda NMC, Andrews AFB, Indian Head, NOP, Dahlgren, NWL, Cheltenham NCS, Ft. Detrick, Patuxent NAS, Washington, D.C. MCRTL, Andrews AFB |
| 9 | <u>Fort Eustis, Virginia</u> : Ft. Lee, Little Creek NAB, Norfolk NAS, Langley AFB, Norfolk DA, Ft. Story |
| 10 | <u>Fort Bragg, North Carolina</u> : Pope AFB |
| 11 | <u>Sunny Point AD, North Carolina</u> : Myrtle Beach AFB |
| 12 | <u>Fort Jackson, South Carolina</u> : Shaw AFB |
| 13 | <u>Charleston AD, South Carolina</u> : Charleston NAS, Charleston AFB |
| 14 | <u>Fort Gordon, Georgia</u> |
| 15 | <u>Fort McPherson, Georgia</u> : Atlanta AD, Athens NSCS, Anniston AD, Fort McClellan |
| 16 | <u>Americus, Georgia</u> : Ft. Benning, Robins AFB, Albany NAS |
| 17 | <u>Fort Stewart, Georgia</u> : Glynco NAS |
| 18 | <u>Jacksonville, Florida</u> : Mayport NAS, Jacksonville NAS, Cecil Field NAS |
| 19 | <u>Lakeland, Florida</u> : Orlando NTC, McCoy AFB, MacDill AFB |
| 20 | <u>Homestead AFB, Florida</u> |
| 21 | <u>Fort Rucker, Alabama</u> |
| 22 | <u>Eglin AFB, Florida</u> : Tyndall AFB, Pensacola NAS |
| 23 | <u>Columbus, Mississippi</u> : Columbus AFB, Meridian NAS |
| 24 | <u>Redstone Ars, Alabama</u> |
| 25 | <u>Memphis, Tennessee</u> : Memphis NAS, Blytheville AFB |
| 26 | <u>Fort Campbell, Kentucky</u> |
| 27 | <u>Kingsport NRTC, Tennessee</u> |
| 28 | <u>Fort Knox, Kentucky</u> |
| 29 | <u>Fort Benjamin Harrison, Indiana</u> : Grissom AFB |
| 30 | <u>Lockbourne AFB, Ohio</u> : Wright-Patterson AFB, Neward AFS |
| 31 | <u>Detroit Ars., Michigan</u> |
| 32 | <u>Appleton MCRTC, Wisconsin</u> |
| 33 | <u>Rock Island Ars., Illinois</u> : Savanna AD, Peoria MCRTC, Burlington NRTF |
| 34 | <u>Great Lakes NTC, Illinois</u> : Glenview NAS, Gary MCRTC |
| 35 | <u>Scott AFB, Illinois</u> |
| 36 | <u>Fort Leonard Wood, Missouri</u> |
| 37 | <u>Fremont NRTF, Nebraska</u> |
| 38 | <u>Emporia, Kansas</u> : Ft. Riley, Forbes AFB, McConnell AFB |
| 39 | <u>Oklahoma City, Oklahoma</u> : Tinker AFB, Vance AFB |
| 40 | <u>Fort Sill, Oklahoma</u> : Altus AFB, Sheppard AFB |
| 41 | <u>McAllister NAD, Oklahoma</u> |
| 42 | <u>Pine Bluff Ars, Arkansas</u> : Little Rock AFB |

*DA Pamphlet No. 210-1, "U.S. Army Installations and major activities in the continental United States." May 1970.

*The installation or city underlined was used as the center of the circular zone on Figure 13.

43 Red River AD., Texas
 44 England AFB, Louisiana
 45 New Orleans NAS, Louisiana: Keesler AFB
 46 Ellington AFB, Texas
 47 Corpus Christi NAS, Texas: Chase Field NAS
 48 Laredo AFB, Texas
 49 Fort Sam Houston, Texas: Kelly AFB, Lackland AFB, Brooks AFB, Randolph AFB, Bergstrom AFB
 50 Fort Hood, Texas
 51 Fort Worth, Texas: Ft. Wolters, Carswell AFB, AERO MTCE, Dallas NAS
 52 Laughlin AFB, Texas
 53 Webb AFB, Texas
 54 Bledsoe, Texas: Cannon AFB, Reese AFB
 55 Fort Bliss, Texas: Holloman AFB
 56 Kirtland AFB, New Mexico
 57 Fort Carson, Colorado: Ent AFB DA, Petersen Field, Lowry AFB, Fitzsimmons AH, Pueblo AD
 58 Ellsworth AFB, South Dakota
 59 Grand Forks AFB, North Dakota
 60 Minot AFB, North Dakota
 61 Malstrom AFB, Montana
 62 Mountain Home AFB, Idaho
 63 Tooele AD, Utah: Hill AFB
 64 Fort Wingate, New Mexico
 65 Fort Huachuca, Arizona: Davis-Monthan AFB
 66 Luke AFB, Arizona: Williams AFB
 67 Navajo AD, Arizona
 68 Yuma P.G., Arizona: Yuma MCAS, El Centro NAF
 69 San Diego NAS, California: North Island NAS, Coronado NAB, Miramar NAS, Camp Pendleton, Imperial Beach NAS
 70 Pasadena, California: George AFB, Norton AFB, March AFB, Port Hueneme, Long Beach NAS, Point Mugu NAS, Edwards AFB
 71 China Lake NWC, California
 72 Nellis AFB, Nevada
 73 Vandenberg AFB, California
 74 Fort Ord, California: Hunter-Liggett Mil. Res., Presidio of Monterey
 75 Centerville NAS, California: Lemoore NAS, Castle AFB
 76 San Francisco, California: Hunter's Pt. NSY, Presidio of San Francisco, Moffett Field NAS, Alameda NAS, Travis AFB, San Bruno MCRTC, Concord NWS, Mare Island NSY & NSCOLCOM, Two Rock Ranch Station, San Francisco NRTC, NS and NC
 77 Beale AFB, California: McClellan AFB, Mather AFB, Sacramento AD
 78 Fallon NAAS, Nevada
 79 Sierra AD, California
 80 Umatilla AD, Oregon
 81 Portland MCRTL, Oregon
 82 Seattle, Washington: Whidby Island NAS, Puget Sound, NSY McChord AFB, Ft. Lewis, Keyport NTS

Table 7 Appendix A (FOUO) similarly presents the Army's FY 73 planned construction for each of the 6 building types.

Appropriation of Funds

The planned construction summarized in this report is subject to review and alteration at several levels: the individual service, DOD and Congress. Normally the total dollar value of approved construction is 50-60 percent of the planned construction given in the source documents for this report. That is to say, some bases may receive only a fraction of their programmed construction allotment, other may receive none at all, while more fortunate bases may be fully funded.

DETERMINATION OF PRODUCTION COMPATIBILITY

The production compatibility of each firm was determined by the following procedure:

1. Each firm was categorized by the degree to which it provides a complete building system. Only those providing at least the building enclosure were considered for further compatibility classification, since comparison of small percentages of a building cost with total planned project costs would not be consistent.

2. The minimum dollar volume to justify a production run for each firm was then identified. (Fig. 15 illustrates surveyed industry response.)

3. It was found that the total dollar volume of planned construction within each of the 82 zones and for each of 3 pairs of building types was far in excess of the minimum identified in No. 2 above. All firms within all zones would be able to justify production providing they were able to produce for a sufficient proportion of the 5 year program.

4. A listing by zones of those firms classified as production compatible was generated based upon the planned construction in FY 73. Due to the varying amounts of planned construction in each of the 6 building types, these types were combined into 3 pairs of similar buildings. They are: Administration-Classrooms, Storage-Auto Repair, and BOQ-EM Barracks. For each zone, each firm's minimum production volume was then compared to the planned construction for each pair of building types.

Although only those firms producing at least the building enclosure were considered for compatibility classification, the information available on the remaining firms would allow the creation of a list of firm combinations that could potentially offer complete building systems for each zone. The combinations of firms in the supplier/manufacturer category would be the prime consideration as the inherent mobility of Architect/Engineer, Construction Manager and Subcontractor/Erector categories permits their services to be utilized on a nationwide basis.

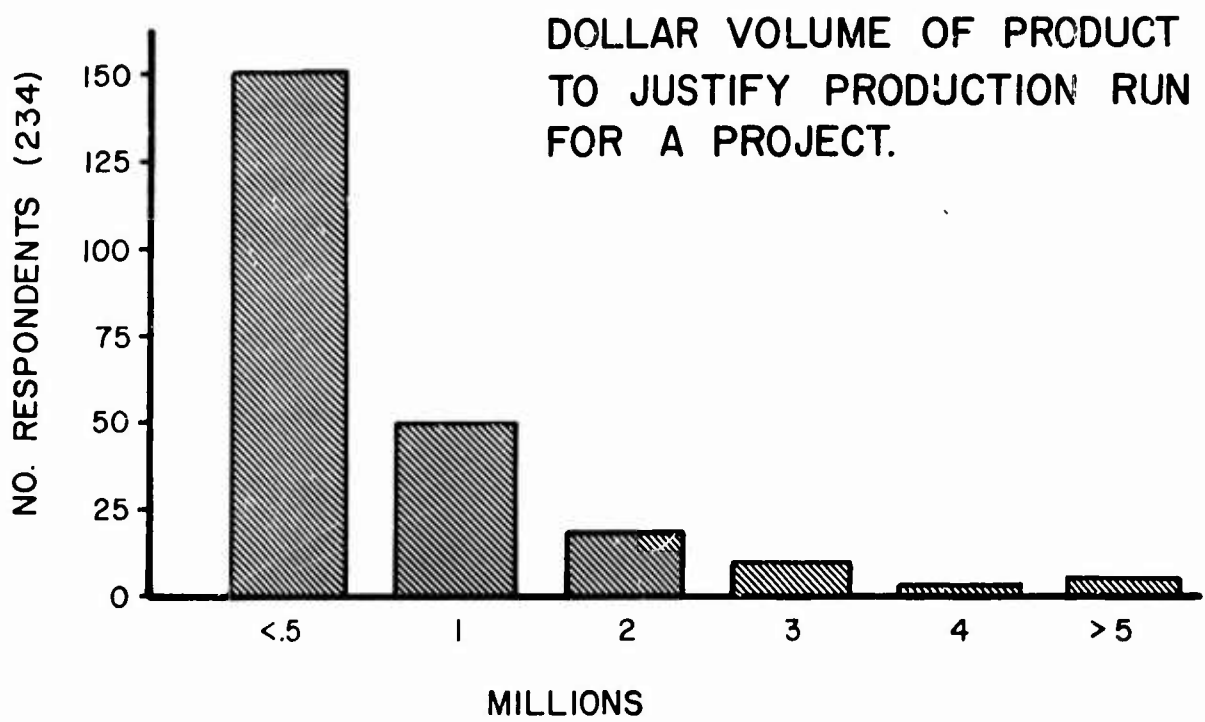
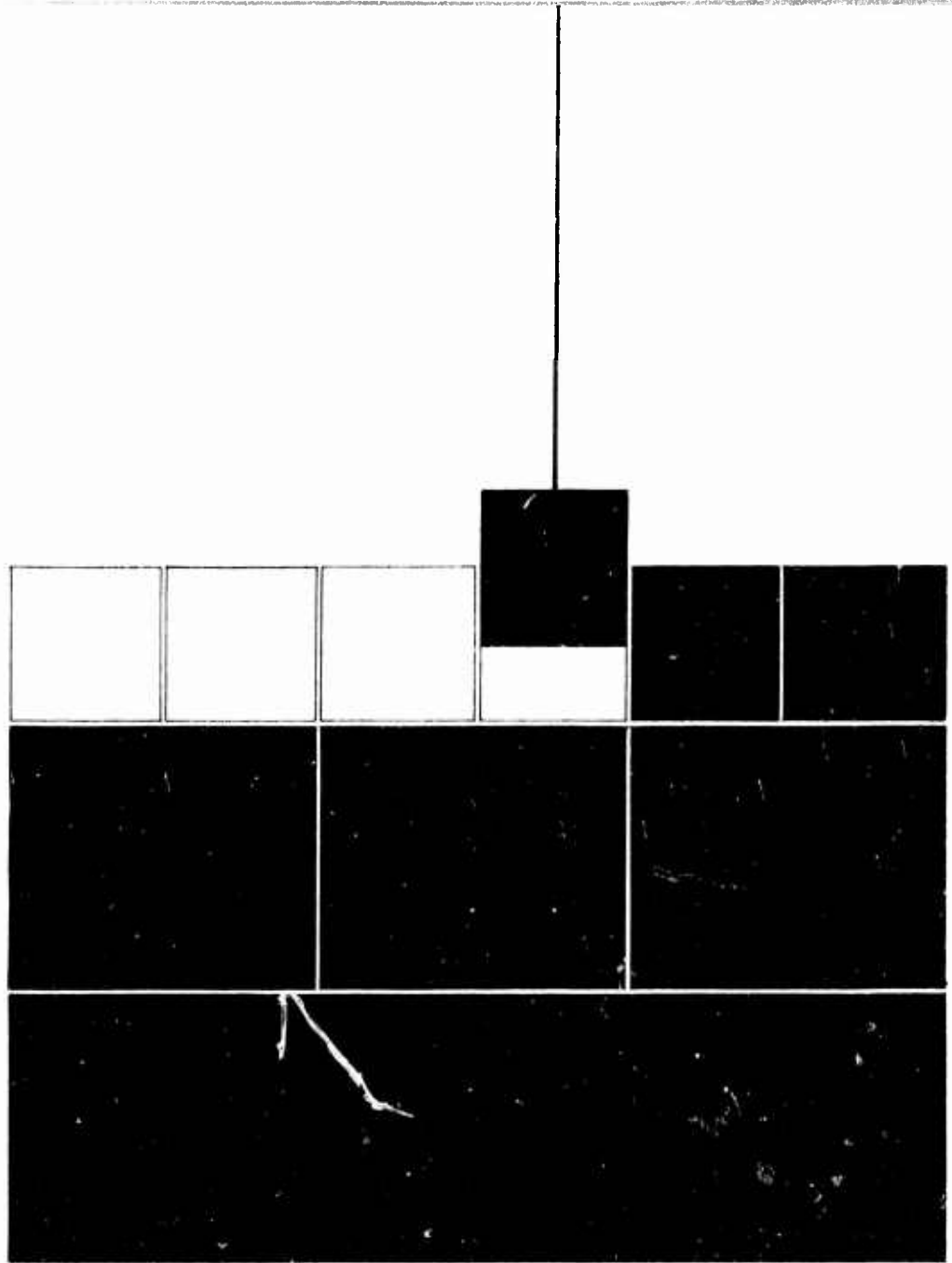


FIGURE 15



feasibility
7

CHAPTER 7: MILITARY BUILDING PROGRAM (1973-77):

FEASIBILITY OF INDUSTRIALIZED BUILDING

On the basis of the criteria outlined in the preceding 3 chapters, each respondent firm was classified into 8 mutually exclusive categories: namely,

1. Design compatible, but not procurement or production compatible;
2. Design and procurement compatible, but not production compatible;
3. Procurement and production compatible, but not design compatible;
4. Design and production compatible, but not procurement compatible;
5. Procurement compatible, but not design or production compatible;
6. Production compatible, but not design or procurement compatible;
7. Not production, design or procurement compatible; and
8. Design, production and procurement compatible.

A complete listing of categories 1, 2, 3, 4, 5 and 8 may be found in Tables 1 through 6 Appendix B (FOUO) (categories 6 and 7 contained 79 and 66 firms respectively).

As Appendix B (FOUO) suggests, only 24 firms within the continental United States have the requisite designs, procurement policies, and production capacities to meet all immediate Department of Defense Military installation needs. The geographical areas served by each of these firms are diagrammed in Figures 16-28.

An additional 25 firms proved conditionally feasible* for particular military building needs.

Since 1) recommended changes in DOD Criteria (described in Appendix A) strengthen—not dilute current design regulations and 2) the benefits obtained through competitive procurement far outweigh the advantages gained through the use of some methods preferred by industry, responsibility for expanding the number of acceptable firms rests primarily with industry, rather than government.

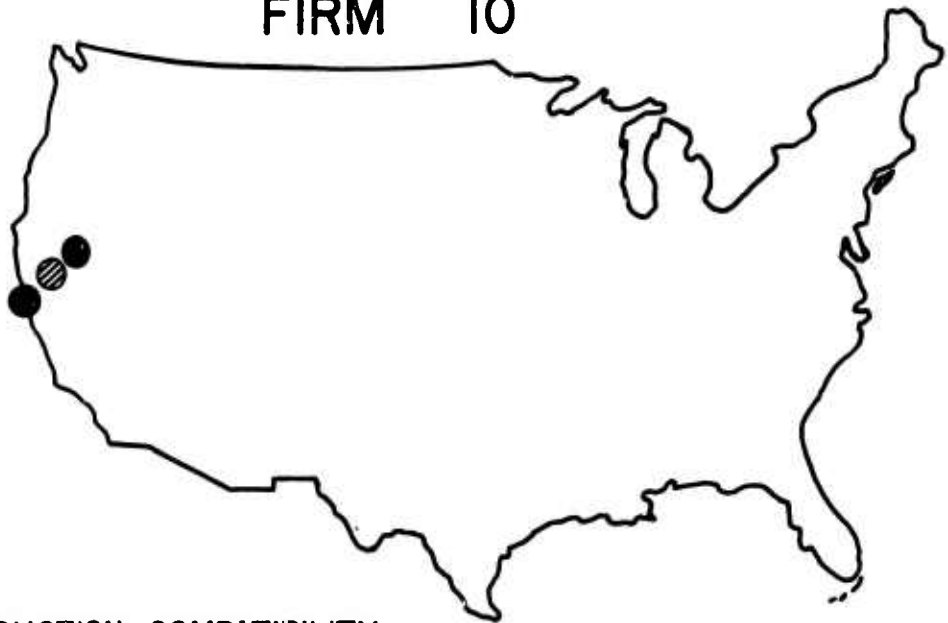
Inasmuch as many of the requisite design modifications are relatively minor, it is conceivable that 49 additional firms could be added to this list. These firms are listed by name in Tables 3 and 5 Appendix B (FOUO).

One unfavorable reflection on the current state of the industrialized building industry is the fact that 25 percent of all industrialized building firms responding to the original survey could not meet any of the criteria outlined in Chapters 4, 5 and 6. Since it is reasonable to assume that few of the 52 percent of the firms who chose to ignore the initial survey solicitation could meet these same rigid standards, this study would suggest that sanguine estimates of the current capabilities of the industrialized building industry are greatly distorted by the large number of "paper" systems on the market.

While the number of presently compatible firms may prove adequate in some localities, other regions are so poorly situated in relation to the location of industrialized builders that the economic feasibility of industrialized projects appears highly improbable. This phenomenon will be examined in detail in the following chapter.

*That is to say, feasible only for particular building types in certain restricted climatic regions of the United States.

FIRM 10



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 11



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 16

FIRM 25



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 49



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 17

FIRM 65



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 82



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 18

FIRM 101



- PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73
- ▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

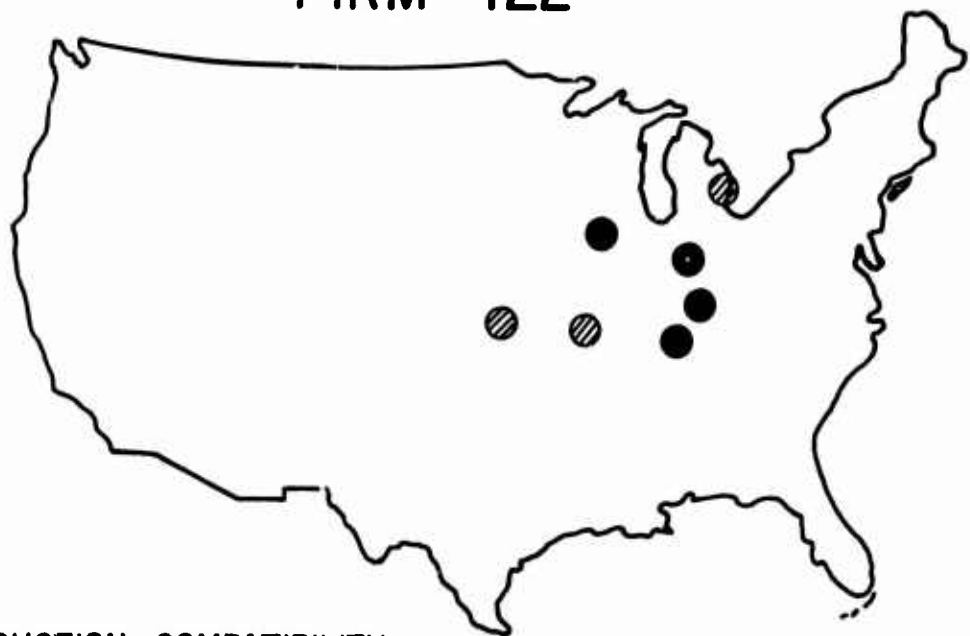
FIRM 121



- PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73
- ▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 19

FIRM 122



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 152



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 20
2-72

FIRM 161



- PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73
- ▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 212



- PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73
- ▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 21

FIRM 235



- PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73
- ▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 258



- PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73
- ▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 22

FIRM 262



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 287

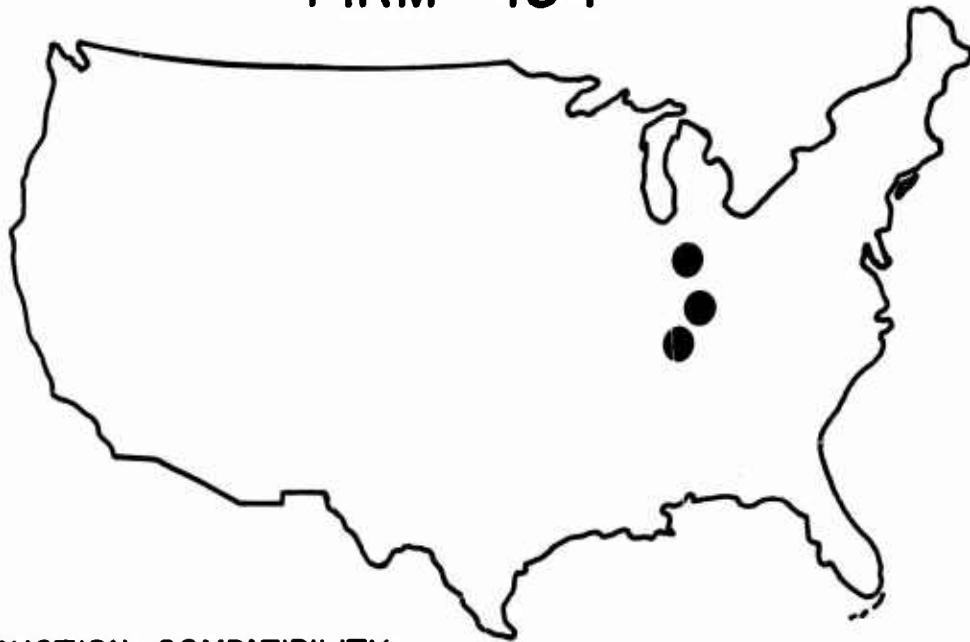


● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 23

FIRM 454



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 475



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 24

FIRM 50I



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 56I



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 25

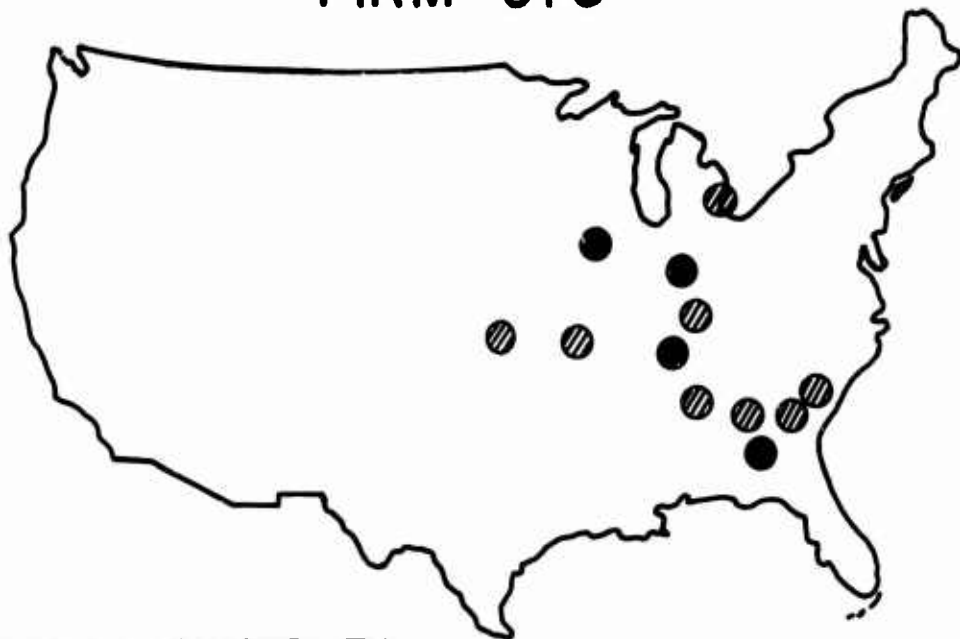
FIRM 562



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 576



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 26

FIRM 590



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 599



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

▨ PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 27

FIRM 620



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

● PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIRM 645



● PRODUCTION COMPATIBILITY
IN ZONE FOR FY. 73

● PRODUCTION COMPATIBILITY
IN ZONE FOR FY'S 73-77

FIGURE 28



implementation
8

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CHAPTER 8 – IMPLEMENTATION OF INDUSTRIALIZED BUILDING

FINDINGS

Using the design-production-procurement compatible systems identified in Chapter 7 as a point of departure, it was possible to identify those portions of the Fiscal Year 1973 programmed construction which were most likely to be amenable to the use of industrialized building systems.

Figure 29, for example, summarizes Figures 16 through 28 of the preceding chapter to delineate all geographical regions served by one or more acceptable (feasible) industrialized building systems.

Assuming (all other things being equal) that competition among industrialized building firms would yield commensurate reductions in total building costs, this diagram suggests that Midwest and Mid-atlantic military installations could be economically provided with feasible industrialized building systems.

In particular, industrialized building programs would be most likely to yield cost savings during Fiscal Year 1973 if initiated at the following installations: Fort Benjamin Harrison, Fort Knox, one or more of the posts found in Zone 8 (Edgewood Arsenal, Fort Meade, Vint Hill Farms, Fort Belvoir, Fort Myer, Fort McNair, Fort Detrick), the Rock Island Arsenal, the Savanna Army Depot and Fort Campbell, Kentucky.

These recommendations change only slightly when recast in terms of a 5 year CONUS construction program. Figure 30, for example, suggests that several additional geographical areas could be served by these same feasible industrialized building firms if projected appropriations for a 5 year period were awarded in lump sum packages. However, the same regions manifesting a superiority in the Fiscal Year 1973 comparisons again reemerge in the intermediate range appropriations schedule.

Such a finding suggests that one conceivable way to increase the potential of industrialized building for military installations would be to rearrange the scheduling of projected installation improvements. Alternatively, Army, Navy and Air Force building programs could be combined in proximate locations to generate larger building markets.

Failing these two possibilities, the joint production of structures for both civilian and military markets might prove to be still a third method for accomplishing the same objective.

The following section contains a detailed examination of this latter alternative.

THE DEMAND FOR NON-MILITARY PUBLIC BUILDINGS SIMILAR IN FUNCTION TO FACILITIES REQUIRED ON U. S. MILITARY INSTALLATIONS

An effort was made by CERL to ascertain the feasibility of coordinating the industrialization of the 6 military building types with needs arising in other public agencies within the regions previously identified as being amenable to industrialized building.

Specifically, CERL attempted to:

1. Identify buildings procured by non-military Federal, state and local agencies which are similar to facilities required on U. S. Military installations.
2. Determine the programmed construction of these representative building types; and
3. Identify and project the demand for similar facilities arising in state and local governments, etc., within the next 5 years (1971-1976).

Methodology

In fulfillment of the stated objectives, CERL representatives interviewed 30 public agencies within a 50 mile radius of the 4 Class I Army installations deemed most amenable to the introduction of industrialized building: Fort Belvoir, Virginia, Fort Knox, Kentucky, Fort Benning, Georgia and Fort Ord, California (see Fig. 31). A sample interview outline of typical questions asked of each of the 30 non-military agencies is presented in Appendix E.

FY 73 PROGRAM

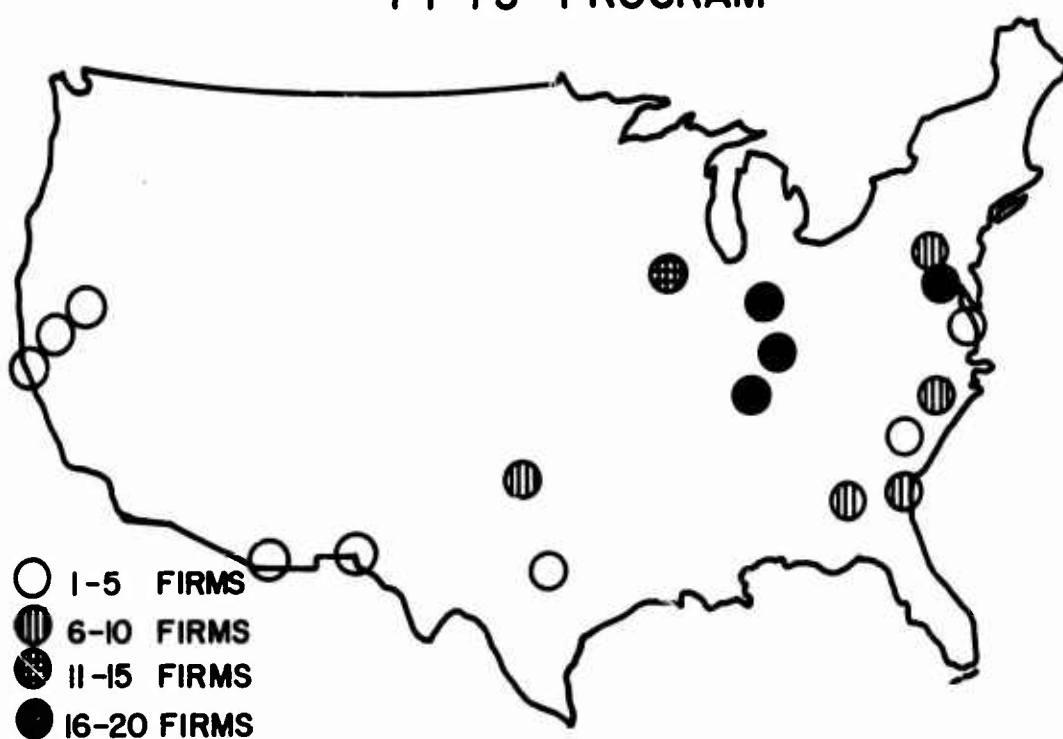


FIGURE 29

FY 73-77 PROGRAM

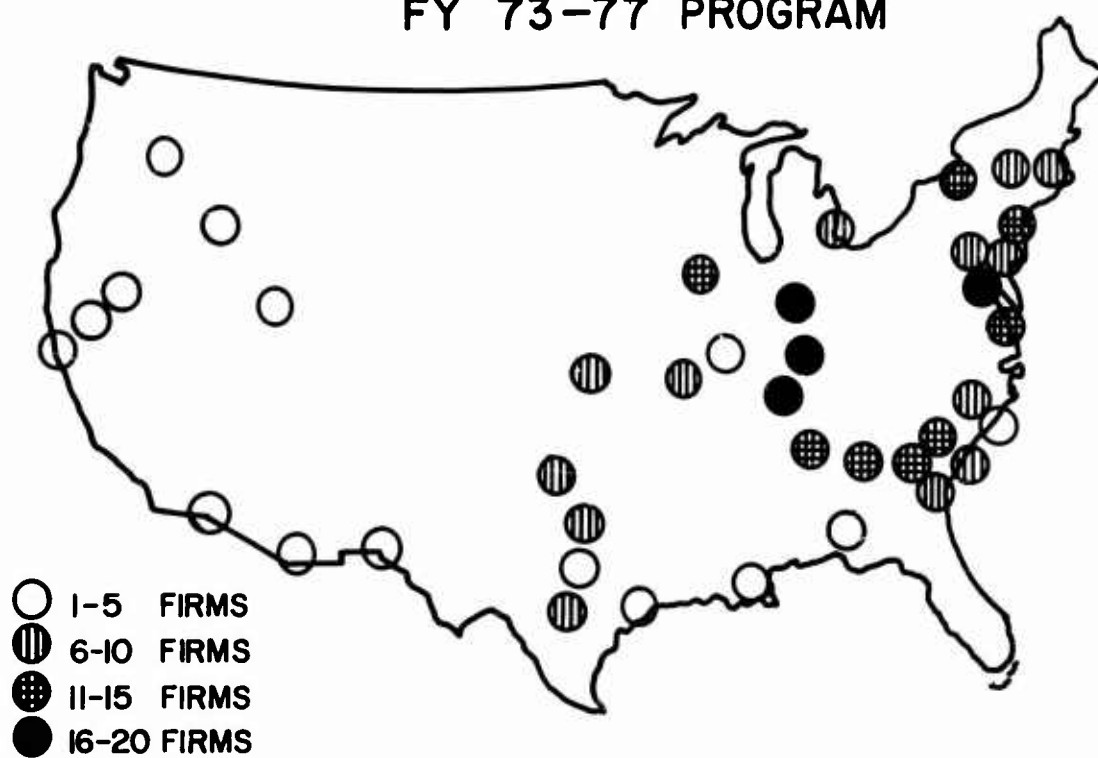


FIGURE 30

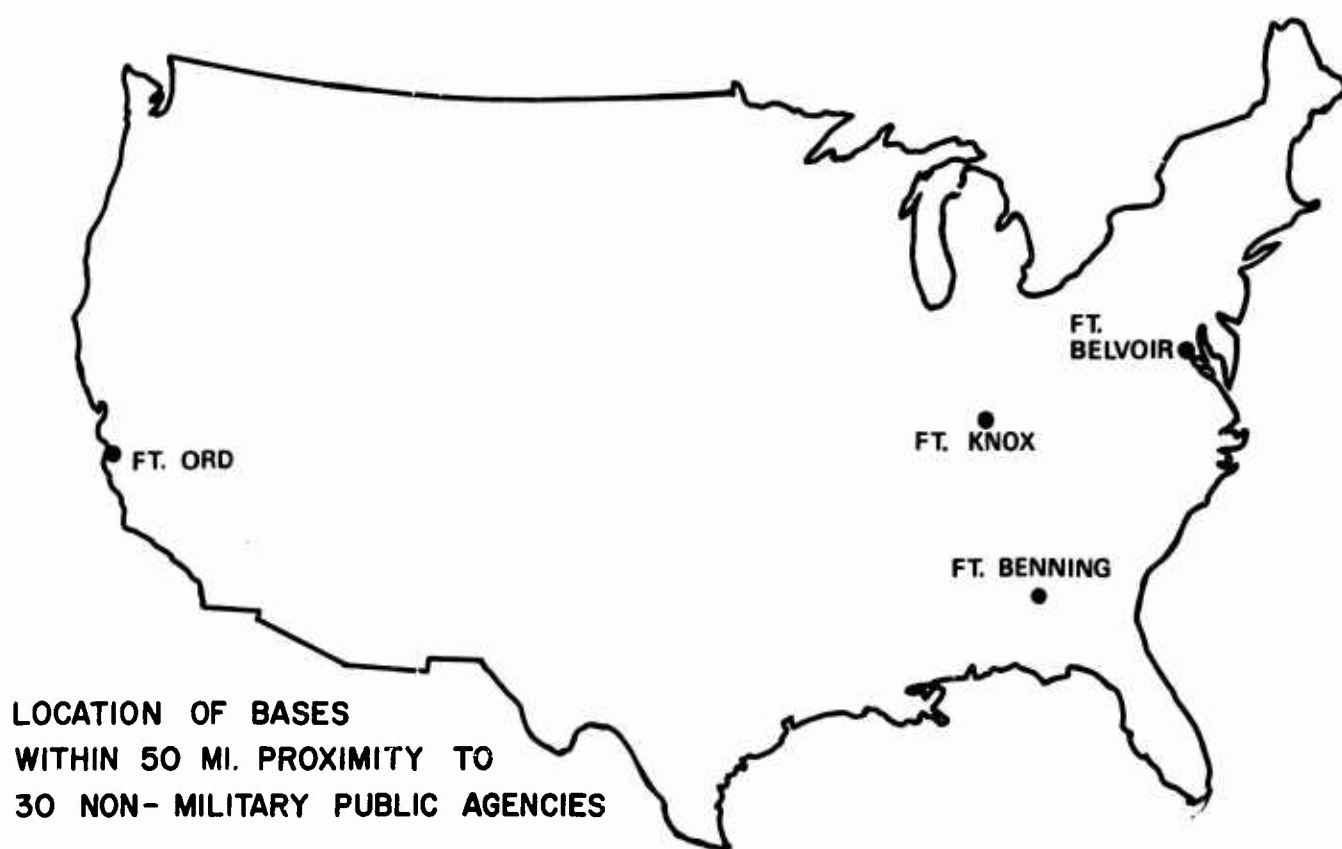


FIGURE 31

Capital Budgeting Requirements for 30 Non-military Public Agencies

The public agencies selected for the survey on the demand for non-military buildings similar in function to those required on Class I Army installations included state universities and colleges, public school districts, county and city planning authorities and others for which the probability of programmed construction could be anticipated.

The public agencies in the vicinity of Fort Belvoir, Virginia received the most attention and yielded the best results. A total of 16 contacts were made in the metropolitan Washington, D.C. area, with the balance distributed among the 3 remaining installations.

Appendix E presents the programmed construction plans for each of the 30 selected public agencies, a summary of each individual interview, (the agencies are grouped alphabetically with geographical area to facilitate presentation) and a mathematical model developed to estimate the total extent of non-military public needs in the four study areas.

Processing the survey data presented in Tables 1 and 2 through Equations 4.2-4.4 and 4.5 of Appendix I yielded the following results:

Survey Results and Projected Total Non-Military Public Building Construction, 1971-1976
in the Vicinity of Class I U. S. Army installations.

| | Survey Results (Millions) | Estimated Total Non-Military Public Buildings (Millions) |
|--------------|---------------------------|-------------------------------------------------------------|
| Fort Belvoir | \$1,355.4 | \$2,822.5 |
| Fort Knox | 80.0 | 122.5 |
| Fort Benning | 40.0 | 53.5 |
| Fort Ord | 16.9 | 404.5 |

A comparison of the survey results and the derived projections of the total demand for non-military public buildings produced the following observations:

Firstly, the survey results are directly proportionate to the projected totals in the same ratio as the number of public agencies surveyed is to the total number of public agencies in each local area. In other words, 16 public agencies in the Fort Belvoir area constitute approximately 50 percent of all fund dispensing public agencies in the 50 mile effective radius for Fort Belvoir. Similarly, the survey results provided approximately 50 percent of the total projected demand.

Secondly, the survey results are for 6 specific building types while the total projected demand is for all possible public building types. However, any under-estimation of the total projected demand could be directly associated with specific building types which were inadequately considered in view of the fact that the demand was made a function of the effects of population change on the 6 building types.

Finally, for completion of the analysis a word is required about the supply of public buildings in contrast with the demand for public buildings. The number of public buildings actually constructed is not only a response to a recognized need or demand for public buildings, but it is also dependent upon the availability of funds via taxation and bond issues.

The amount of public funds to be used for construction of public building is, in effect, an allocated amount from total revenue. The allocation of public monies to their purposes, such as teachers' salaries, is an indirect function of the effects of population changes, just as the demand for public buildings is dictated by population changes. In the final analysis, the demand for public buildings is merely a part of the total demand for public services.

INTERPRETATION OF STUDY FINDINGS

This study of industrialized building has implications for three fundamental policy areas: design criteria, procurement regulations and construction programming. Each shall be discussed in turn.

Design Compatibility

An investigation of the comparison of DOD Construction Criteria and the Recommended Standards for elements, subsystems, and components as contained in Appendix A reveals the following general observations:

1. DOD criteria and the recommended standards are complementary, rather than conflicting.
2. DOD criteria does not include standards for many significant industrialized building elements. The appropriateness of performance requirements for building systems description warrants the removal of reference to specific materials.
3. Many DOD standards are inconsistent with the nationally accepted model building codes commonly adhered to by the industrialized building industry.
4. Requirements peculiar to industrialized building need to be added to DOD criteria, i.e., performance requirements, interface requirements, dimensional coordination, etc.).

Procurement Compatibility

Significant of the responses of those surveyed was the lack of willingness or usual policy of contracting directly with the owner (Fig. 32). Although it is recognized that many of these firms would, under the proper conditions, be willing to sell their product directly to the owner, the trend towards central management of projects and increasing use of construction management firms in the industrialized process reveals a contrast to present project management within Government construction procurement methods.

Production Compatibility

As was stated earlier, a scarcity of firms in some regions of the Nation preclude the economical use of industrialized building. Conversely, there are regions in the United States (containing adequate numbers of building manufacturers) without sufficient programmed military construction to justify industrialized methods.

The study of the demand for non-military public buildings similar in function to facilities required on U. S. Military installations suggests that such a demand is both recognizable and programmatically acceptable to a limited degree. Although there is considerable need for the education and persuasion of public officials with regard to industrialized buildings, the effort to establish consortia for the mass purchasing of industrialized building components is feasible.

(Appendix C (FOUO) summarizes the results of this study by including known dollar values of programmed military construction for the four geographical areas investigated.)

62 % OF FIRMS WILL NOT SELL PRODUCT
DIRECTLY TO OWNER, BUT WILL
CONTRACT WITH:

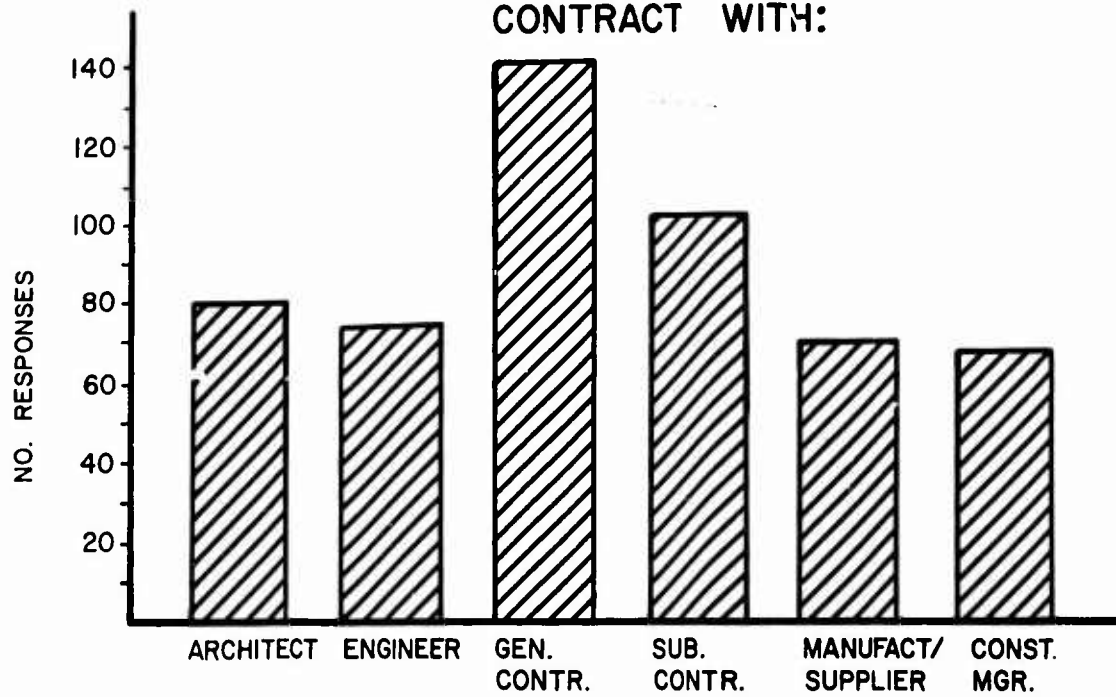
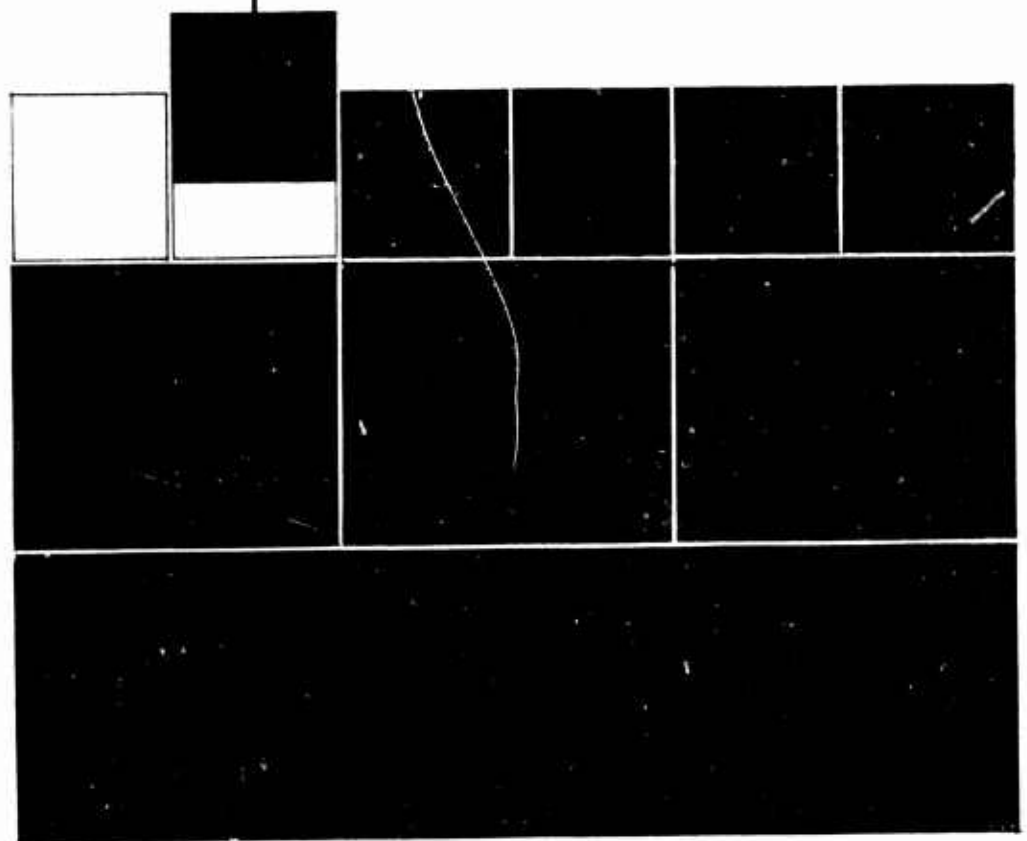


FIGURE 32



cost and time analyses

CHAPTER 9 : COST STUDIES

COST COMPARISONS OF INDUSTRIALIZED AND CONVENTIONAL CONSTRUCTION

Introduction

A fundamental impetus to the growth in popularity of industrialized building has been the widely shared belief that industrialized building costs less than conventional construction. In this chapter the validity of this proposition for selected Army facilities will be explored.

Cost Data Collection

Although much cost information is available in the popular literature, little of it is complete, verifiable, or directly applicable to the special case of buildings commonly found on U. S. Military installations.

To acquire reliable data, CERL solicited cost information (together with detailed information on the characteristics of the buildings) from over 100 respondents to the original questionnaire on projects actually constructed within the past two years. (An example of this survey may be found in Appendix G) Over 90 percent of the respondents replied to this second solicitation, producing 89 usable pieces of data. Most of the data so provided pertained to group dwelling quarters and classroom type structures.

Study Procedures

The cost data were adjusted to a common 1970 price level using the Engineering News Records' Construction Index.

Next, the cost data was related to design characteristics of the buildings—such as height, width, number of rooms, etc.—by a statistical technique known as multivariate regression analysis.*

Thirdly, historical cost data pertaining to the 6 representative building types were collected from the Specifications and Estimating Branch of the Engineering Division within the Directorate of Military Construction of the Office of the Chief of Engineers (ENGMC-ES). The physical dimensions of these 6 representative building types were then inserted into the cost equations derived in the regression analysis phase to obtain an estimate of the costs of constructing an equivalent industrialized building.

Finally, these cost estimates for producing similar-sized industrialized products were compared to the average realized costs of constructing the same facilities with conventional construction techniques to derive conclusions regarding the relative costs of industrial and conventional construction.

The remainder of the chapter discusses each of these steps in detail.

Data Preparation and Analysis

Since each of the 6 representative building types selected for analysis were rectangular, all collected data pertaining to irregular-shaped buildings were discarded, leaving 35 usable observations on buildings similar to configuration to Army structures.

These 35 observations were subsequently stratified into one, two and three story height classes.

Because of the limited number of observations remaining within each homogenous height-configuration class, total building costs in each case were then regressed upon only a single independent variable—building volume (measured in cubic feet)—to produce 3 linear regression models of the general form: $\text{Cost} = A + B (\text{Volume})$, where A, B are fixed parameters. That is to say,

*Briefly explained, regression analysis is a method for relating one or more "independent" variables, or "explanatory" variables to a single "dependent" variable by a process of "curve-fitting." Plotted in Figure 33, for example, are 11 of the reported relationships between total building cost and total building volume. In this diagram, building cost generally tends to increase as the building volume increases. As shown in Figure 34, one possible representation of the relationship between building volume and building cost is a linear relationship of the form $\text{Cost} = A + B (\text{TBV}) \pm E$ where TBV is the total building volume, A and B are constants and E is the random error. Utilizing this form of linear relationship, total adjusted industrialized building costs were functionally related to several of the physical characteristics of the industrialized buildings themselves.

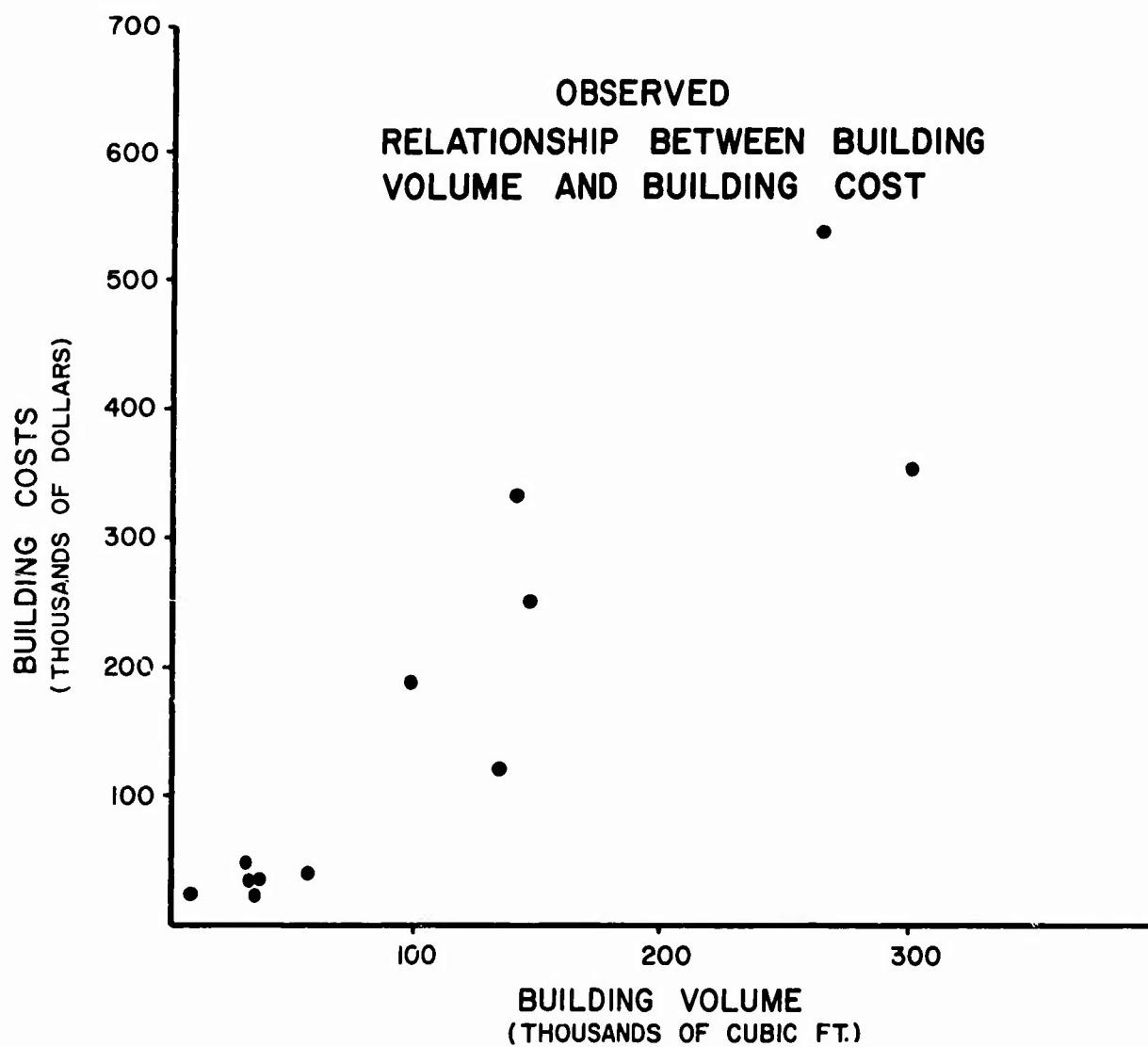


FIGURE 33

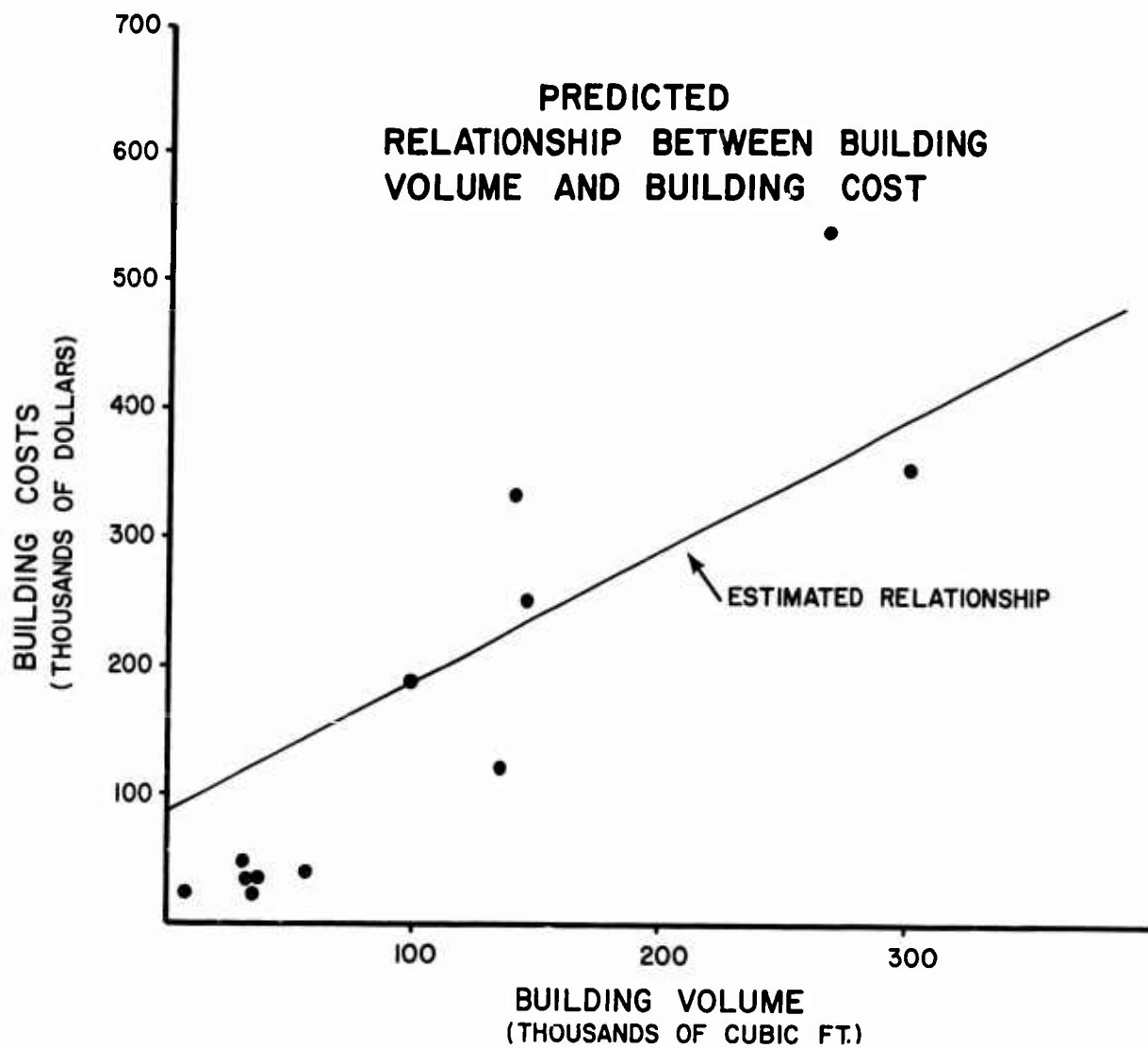


FIGURE 34

For Single Story Buildings

$$(1) \quad C = 117,636 + 0.96586 (TBV);$$

(13.9)

$$\begin{aligned} R^2 &= .926 \\ N &= 15^{**} \\ SEE &= 332,548^{***} \end{aligned}$$

Where C = Total Building Cost (in 1970 dollars)
 TBV = Total Building Volume (in cubic feet)

For Two Story Buildings

$$(2) \quad C = 272,426 + 1.158698 (TBV)$$

(3.48)

$$\begin{aligned} R^2 &= .524 \\ N &= 11 \\ SEE &= 525,214 \end{aligned}$$

And For Three Story Buildings

$$(3) \quad C = 542,200 + 0.74102 (TBV)$$

(6.71)

$$\begin{aligned} R^2 &= .549 \\ N &= 33 \\ SEE &= 1,172,435 \end{aligned}$$

Conventional and Industrialized Building Cost Comparisons

These 3 equations relating total industrialized building costs to total building volume provided a basis for making relative cost comparisons with conventional construction.

The physical volumes of barracks, bachelor officer quarters, and maintenance and repair facilities were calculated from standard plan drawing numbers 21-01-142, 25-06-72 and 35-02-27 as 485,640 cubic feet, 143,360 cubic feet, and 87,286 cubic feet, respectively.

These volumes, when inserted into the appropriate equation (corresponding to the height of the building in question) yielded the following cost estimates for constructing barracks, BOQ's and M&R Shops with industrialized methods:

Table 1

ESTIMATED COST OF CONSTRUCTING ARMY FACILITIES WITH INDUSTRIALIZED METHODS

| Facility Type | Estimated Cost |
|------------------------------|----------------|
| Barracks | \$887,686 |
| Bachelor Officer Quarters | \$438,537 |
| Maintenance and Repair Shops | \$201,936 |

A comparison between these costs and actual costs experienced by the Corps of Engineers in building these same structures by conventional methods may be found in the accompanying Tables 2, 3 and 4.****

In Table 2 for example, the average cost of constructing three story barracks during the past 6 years has been \$824,467 (in terms of 1970 prices) or 7.67 percent below the price which would have been experienced had the Corps chosen to utilize industrialized methods. When both extreme high and low cost conventional projects are eliminated from consideration, moreover, the probable extra cost increases to 11.2 percent.

In a similar fashion Tables 3 and 4 indicate that constructing Bachelor Officer Quarters with industrialized methods would cost 14.3 percent more (although the sparseness of conventional cost data does not warrant great confidence in this prediction) while constructing maintenance and repair facilities with industrialized products could possibly cost the government 70 percent more than the traditional methods it now utilizes.

*Percentage of Cost Variation explained or accounted for by linear equation.

**Number of observations. Since only 8 three story observations were available in equation (3) for analysis—too few for accurate estimation—this regression was derived by pooling all 3 data sets and inserting dummy variables for two and three story buildings.

***SEE = Standard Error of Estimate. 68 percent of all actual industrialized construction costs lie within the interval defined by plus or minus one standard error of estimate from the predicted cost.

****A dearth of historical cost data on classroom type-training facilities, administrative buildings, and storage facilities precluded similar cost comparisons on these building types.

Table 2

**COMPARISONS BETWEEN THE ESTIMATED COST OF CONSTRUCTING
BARRACKS USING INDUSTRIALIZED METHODS WITH THE ACTUAL
COSTS OF CONSTRUCTING BARRACKS USING CONVENTIONAL BUILDING
TECHNIQUES DURING THE PERIOD 1964-1970**

| Facility Location | Year Built | Total Cost (Unadjusted) | Total Cost (Adjusted to 1970 Price Levels) | Estimated Cost Using Industrialized Building Systems |
|------------------------------------------------------------------|------------|----------------------------|-----------------------------------------------------|---------------------------------------------------------------|
| Fort Irwin | 1965 | \$625,185 | \$860,000 | |
| Fort Dix | 1965 | \$536,693 | \$737,000 | |
| Fort Hood | 1967 | \$641,620 | \$811,000 | |
| Fort Gordon | 1967 | \$559,822 | \$709,000 | |
| Fort Knox | 1967 | \$696,353 | \$881,000 | |
| Fort Hood | 1967 | \$554,347 | \$701,000 | |
| Fort Jackson | 1967 | \$548,534 | \$694,000 | \$887,686 |
| Fort Riley | 1967 | \$666,500 | \$844,000 | |
| Fort Dix | 1967 | \$664,000 | \$840,000 | |
| Fort Gordon | 1967 | \$595,000 | \$754,000 | |
| Fort Devens | 1967 | \$825,000 | \$1045,000 | |
| Fort Devens | 1967 | \$827,000 | \$1048,000 | |
| Fort Carson | 1968 | \$659,000 | \$784,000 | |
| Fort Carson | 1968 | \$696,000 | \$824,000 | |
| Fort Riley | 1968 | \$702,000 | \$835,000 | |
| AVERAGE ADJUSTED COST | | | \$824,467 | \$887,686 |
| AVERAGE ADJUSTED COST (Eliminating High and Low Observations) | | | \$798,333 | \$887,686 |

Table 3

COMPARISONS BETWEEN THE ESTIMATED COST OF CONSTRUCTING BACHELOR
OFFICER QUARTERS USING INDUSTRIALIZED METHODS WITH THE
ACTUAL COSTS OF CONSTRUCTING BOQ'S USING CONVENTIONAL
BUILDING TECHNIQUES DURING THE PERIOD 1964-1970

| Facility Location | Year Built | Total Cost (Unadjusted) | Total Cost (Adjusted to 1970 Price Levels) | Estimated Cost Using Industrialized Building Systems |
|-------------------|------------|-----------------------------------------------------------------------------|-----------------------------------------------------|------------------------------------------------------------|
| Fort Rucker | 1964 | \$240,000 | \$344,000 | |
| Fort Leonard Wood | 1964 | \$342,000 | \$475,000 | \$438,537 |
| Fort Rucker | 1965 | \$243,000 | \$332,000 | |
| | | AVERAGE ADJUSTED COST | \$383,667 | \$438,537 |
| | | AVERAGE ADJUSTED COST (Eliminat- ing High and Low Observations) | \$344,000 | \$438,537 |

Table 4

**COMPARISONS BETWEEN THE ESTIMATED COST OF CONSTRUCTING
MAINTENANCE AND REPAIR FACILITIES USING INDUSTRIALIZED
METHODS WITH THE ACTUAL COST OF CONSTRUCTING MAINTENANCE
AND REPAIR FACILITIES USING CONVENTIONAL BUILDING TECHNIQUES
DURING THE PERIOD 1964-1970**

| Facility Location | Year Built | Total Cost (Unadjusted) | Total Cost (Adjusted to 1970 Price Levels) | Estimated Cost Using Industrialized Building Systems |
|------------------------------------------------------------------|------------|----------------------------|-----------------------------------------------------|---------------------------------------------------------------|
| Fort Bragg | 1967 | \$101,005 | \$128,000 | |
| Fort Story | 1967 | \$ 82,671 | \$104,500 | |
| Fort Dix | 1967 | \$116,611 | \$147,000 | |
| Fort Knox | 1967 | \$ 97,032 | \$123,000 | |
| Fort Knox | 1967 | \$129,003 | \$163,000 | |
| Fort Dix | 1964 | \$ 92,200 | \$128,500 | \$201,936 |
| Fort Leonard Wood | 1964 | \$ 72,400 | \$100,900 | |
| Fort Leonard Wood | 1964 | \$ 72,100 | \$100,000 | |
| Fort Bragg | 1964 | \$ 52,000 | \$ 72,500 | |
| Fort Dix | 1964 | \$ 62,900 | \$ 87,500 | |
| Fort Jackson | 1964 | \$ 71,400 | \$ 99,400 | |
| Vint Hill Farms | 1965 | \$104,000 | \$142,900 | |
| Fort Campbell | 1965 | \$ 88,000 | \$120,400 | |
| AVERAGE ADJUSTED COST | | | \$118,813 | \$201,936 |
| AVERAGE ADJUSTED COST (Eliminating High and Low Observations) | | | \$118,976 | \$201,936 |

One possible explanation for this discrepancy is that nearly all one story industrialized building cost data pertained to structures embodying higher aesthetics, lighting, plumbing, heating and insulation standards that are normally required for U. S. Army maintenance facilities. If equal standards were applied, this assumption would suggest that the large cost differential would decrease. However, other studies performed by CERL indicated that building type was not a critical determinant of building costs. Therefore, differing criteria per se would appear to have little effect.

ADDITIONAL COST STUDIES

The aggregation of all 35 observations with the three building type-height classes made more sophisticated explorations of the industrialized building process possible. Equation 4, for example, suggests that industrialized building processes are subject to the same seasonality experienced by conventional construction (note the large dollar value which must be added to the constant term if construction was initiated during October, November or December) while equation 5 implies that industrialized construction is cheaper along the warmer coastal regions of the continental United States and relatively more expensive in the Midwest and Northeastern regions of the Nation.

$$(4) \quad C = 231,913 + 890,780 (OND) - 841,860 (AUS) + 1,101,300 (CXW) + 0.66182 (TBV)$$

(2.15) (2.22) (3.14) (7.45)

$R^2 = .783$
 $N = 35$
 $SEE = 882,542$

Where C = Total Building Cost using industrialized methods

OND = Building construction initiated during October, November or December (variable assumes value of 1 or 0 depending upon whether the proposition is true or false)

CXW = Building constructed with Concrete eXterior Walls

TBV = Total Building Volume (in cubic feet)

$$(5) \quad C = 635,514 - 946,270 (SE) - 761,590 (PAC) + 547,580 (SW) + 1,045,800 (OND) - 864,230 (AUS) + 1,288,900 (CXW) + 0.64706 (TBV)$$

(1.22) (1.41) (0.890) (2.54) (2.05) (3.28) (6.67)

$R^2 = .821$
 $N = 35$
 $SEE = 867,208$

Where C = Total Building Cost using industrialized methods (in dollars)

SE = Building constructed in SE part of United States (variable assumes value of 1 or 0 depending upon whether the proposition is true or false)

PAC = Building constructed in PACific coast region of the United States (1 or 0)

SW = Building constructed in SW part of United States (1 or 0)

OND = Building construction initiated during October, November or December (1 or 0)

AUS = Building of an AUstere quality (1 or 0)

CXW = Building constructed with Concrete eXterior Walls

TBV = Total Building Volume (in cubic feet)

Finally, equation (6) asserts that adjusted industrialized building costs have not differed materially from the costs realized in the conventional construction industry throughout time, as evidenced by the small t-ratio values below each of the "year constructed" coefficients (A low t-ratio implies that the estimated coefficients are not "significantly" different from 0 and should be ignored altogether).

$$(6) \quad C = -44,995 + 621,470 (Y66,67) - 380,350 (Y68,69) \\ (0.88) \quad (0.57)$$

$$R^2 = .823 \\ N = 35 \\ SEE = 811,228$$

$$+ 295,190 (Y70,71) - 887,795 (AUS) + 1,026,200 (OND) \\ (0.48) \quad (2.39) \quad (2.65) \\ + 0.73425 (TBV)$$

Where C = Total Building Cost using industrialized methods (in dollars)
 $Y66,67$ = Building constructed in either 1966 or 1967 (variable assumes value of 1 or 0 depending upon whether the proposition is true or false)
 $Y68,69$ = Building constructed in either 1968 or 1969
 $Y70,71$ = Building constructed in either 1970 or 1971
 AUS = Building of an AUStere quality
 OND = Building construction initiated during October, November or December
 TBV = Total Building Volume (in cubic feet)

CONSTRUCTION TIME COMPARISONS

Concomitant with these cost comparisons, efforts were made to estimate the magnitude of total time savings accruing from the use of industrialized building techniques. Construction time was defined to be the interval between the initiation and completion of onsite building construction.

The total construction time (in months) required to complete 34 industrialized building projects were statistically correlated with the size of the overall projects to derive the linear equation:

$$(1) \quad T_{ib} = 5.792 + .00006824 (Ag)^* \\ (4.82)$$

$$R^2 = .421 \\ SEE = 6.276 \\ N = 34$$

Where T_{ib} = Time required to construct project (in months) with Industrialized Building.
 Ag = Area of Ground floor (in square feet)

describing total industrialized building construction time as a function of project size.

Secondly, using the aforementioned conventional construction data provided by OCE, total conventional construction time was related to conventional project ground floor areas, yielding the result:

$$T_{cc} = 11.828 + .00009422 (Ag) \\ (4.89)$$

$$R^2 = .292 \\ SEE = 4.219 \\ N = 60$$

Where T_{cc} = Time required to construct project with Conventional Construction

Since both equations were functions of the same variable—total project ground floor area—the first equation could be solved in terms of the second to produce:

$$(3) \quad T_{ib} = 2.7719 + .7240 (T_{cc}),$$

an equation explicitly comparing industrialized construction time to the erection time required by conventional building techniques. This equation suggests that projects requiring 6 months to construct with conventional building methods would require only 1.57 months to finish with industrialized building techniques, while conventional projects of one year's duration would entail only 5.92 months if built with industrialized methods.

A graphical representation of all possible time comparisons is given in Figure 35.

As the diagram illustrates, substantial time savings would seem to accompany the introduction of industrialized techniques in all military building programs.**

*Ground Floor Area (Ag), was utilized in place of total building volume (TBV) because of its higher correlation with industrialized building time. Insofar as foundations constitute the most time consuming aspect of industrialized site erection, and ground floor area is representative of the total foundation work required, such a result is not surprising.

**It should be noted that such time savings would not be expected to yield lower construction costs than already described above in the preceding sections, since all possible dollar savings arising from lower carrying charges, insurance fees, etc. were accounted for in the final cost data provided by the industrialized builders.

TRADITIONAL AND INDUSTRIALIZED
CONSTRUCTION TIME COMPARISONS

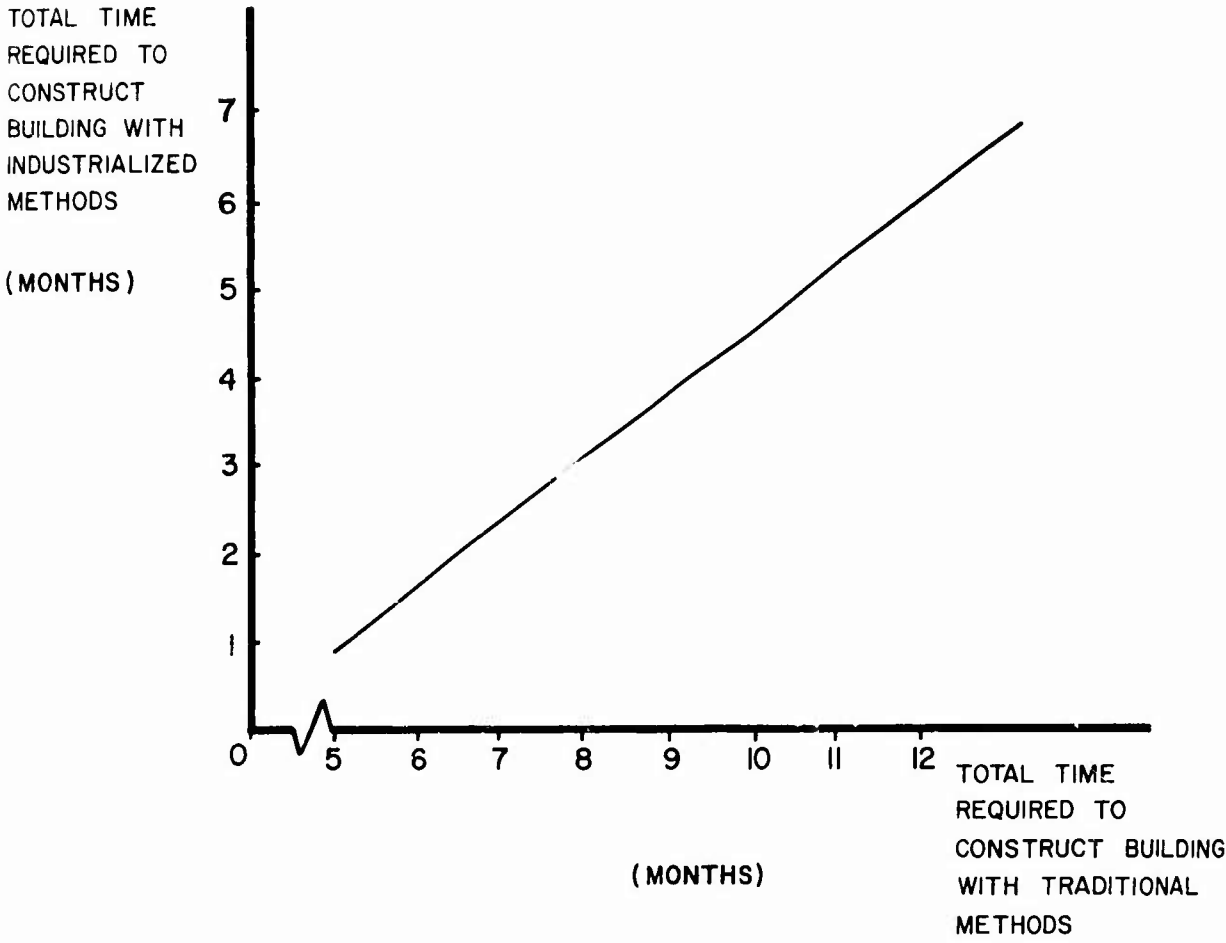


FIGURE 35

These comparisons thus argue strongly for the utilization of industrialized methods whenever time is the most pre eminent consideration.

INTERPRETATIONS OF THE FINDINGS

Precautions should be taken against interpreting these results too literally. Figure 36 suggests, for example, that a large standard error of estimate (SEE), or range of error, is associated with equations (1), (2) and (3) so that the predicted costs are susceptible to a wide variation, far in excess of the slight margins of "cost savings" described previously. Consequently it is impossible to state unequivocally that industrialized building would always be less advantageous to the Army than the conventional construction techniques that it now uses. Rather all findings must be construed in terms of probabilities rather than certainties.

Moreover, even if the estimates themselves are valid at this particular point in time, it does not follow that such findings adequately measure the economic prognosis of industrialized building over time.

Indeed, a United Nations publication, Industrialization of Building concludes, after an exhaustive survey of all European systems, that each nation's industrialized building industry passes through a three stage evolutionary process, characterized by high initial costs in the initial phase, a "weeding out" of noncompetitive systems and consolidation of successful systems during the second stage, and a third stage during which industrialized building costs drop substantially below those experienced by conventional construction. Hence, any long term predictions must await the development of adequate industrialized building cost time-series, which will in turn require subsequent data monitoring, analysis and verification.

Finally, the comparisons contained in Tables 2, 3 and 4 implicitly assume that the environmental quality of industrialized structures is equal to that quality produced by conventional construction techniques. This proposition may in fact not hold true, and until more research is conducted, should be considered only as a hypothesis worthy of further investigation.

CONCLUSIONS

Given the tenuous character of survey cost data, the derived results regarding the relative costs of industrialized building and conventional construction are tentative rather than conclusive. That is to say, it is difficult to assert that industrialized building is either more or less costly than current conventional construction. Further investigation of the efficacy of industrialized building in meeting U. S. military installation needs is therefore desirable and necessary.

INDUSTRIALIZED CONSTRUCTION AND CONVENTIONAL CONSTRUCTION COST COMPARISONS

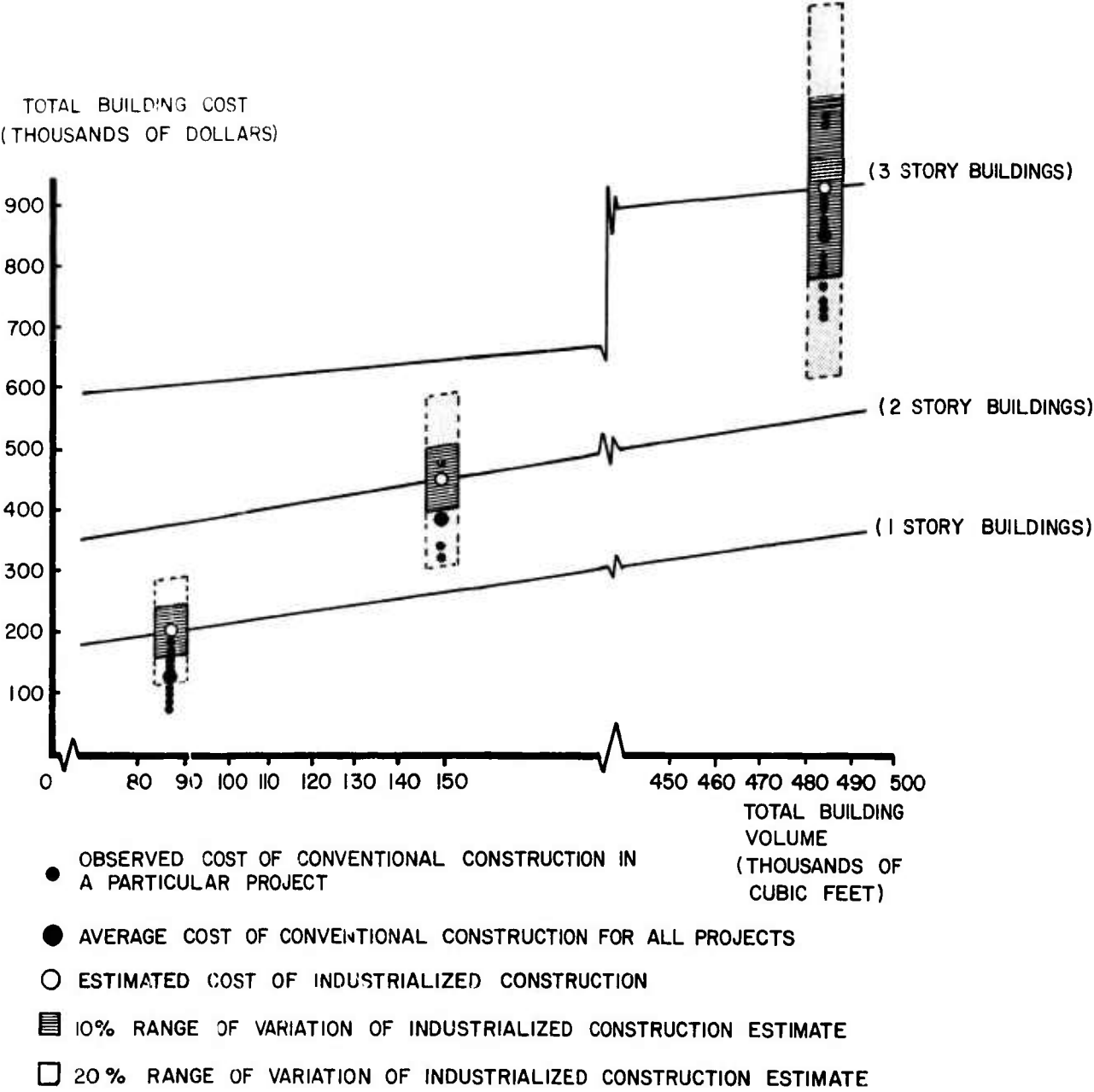
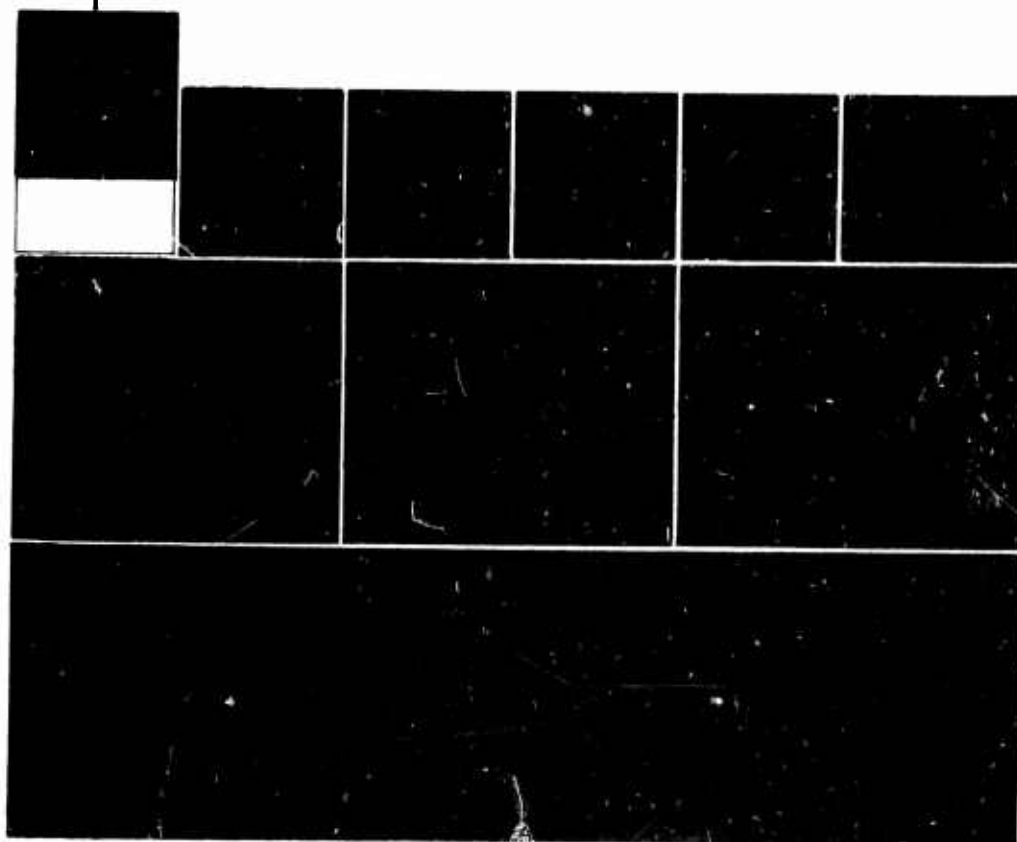


FIGURE 36



facility evaluation

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CHAPTER 10: FACILITY EVALUATION

INTRODUCTION

Procedures for evaluating the performance of conventionally constructed facilities during use are explicitly described in a proposed Engineering Regulation entitled "Design Criteria Feedback Program" (No. 1110-3).*

The purpose of this chapter is to suggest modifications in these procedures permitting application of this directive to all industrialized building systems.

SUMMARY

The central tenets of these recommendations are that (1) performance measures derived from a random sample of industrialized buildings can provide valid representations of the performance of the larger class of all industrialized buildings (i.e., successfully substitute for exhaustive records of the performance of every building in the class studied); (2) that specifically identified attributes of industrialized buildings require special considerations not explicitly recognized in current deficiency reporting systems; (3) that testing procedures can be developed to rank order alternative building design possibilities (such as industrialized versus conventional construction) on the basis of subjective user evaluations; (4) and that such a program can be successfully managed under current COE organizational arrangements.

STANDARDS OF PERFORMANCE

Current DOD Standards of Performance fall into three general classes: Prescriptive Specifications, Performance Specifications, and Non-Commensurable Specifications.

Prescriptive specifications give particular physical solutions to problems (Section 5-3.2). The bulk of current standards are expressed in this form, including many references to prescriptive building codes (Section 8-7.1). Although such standards are useful during initial design stages, they are of little value in the evaluation of a building during its use because there are no associated measures of performance. The user is concerned, for example, with the quality of lighting, not with the gauge of metal used in the lighting fixtures.

Performance Specifications are expressed as measurable expectations of performance. Some performance specifications exist (Section 7-1.3), and more are being proposed (see Chapter 5 "Industrialized Building: Design Compatibility").

Non-Commensurable Specifications are specifications couched in performance terms which are too vague to serve as useful measures (Sections 3-3.1.6, 3-6.3, 5-4.2). They suggest the usefulness of hard measures of performance, but do not explicitly identify them.

These standards, as measures of total building performance are deficient in three fundamental respects: 1) they pertain almost exclusively to product performance, providing few accepted standards for cost performance; 2) Product Performance measures do not cover special difficulties attendant to the introduction of industrialized building systems and; 3) they do not outline procedures by which acceptable measures of functional procedures may be obtained.

SUGGESTED MODIFICATIONS IN DOD STANDARDS

These shortcomings warrant several modifications and additions to current DOD Construction Criteria.

Modifications in Product Performance Criteria

Firstly, although all product performance criteria described in QCR 1.01.006 and DOD Construction Criteria are designed to be independent of the method of construction, several of these performance measures have inordinate significance for structures constructed by industrialized methods and should be amplified.

In addition to normally accepted measures of building performance, total industrialized building evaluation would also consider jointing criteria, flexibility for modernization, alterations for maintenance and repair, and manufacturer replacement and overall policies.

*This ETL essentially outlines the deficiency reporting protocol to be followed by interdisciplinary teams of OCE, District, and Division personnel during periodic inspections of major Army facilities.

For example, although jointing problems are not unique to industrialized construction, these difficulties are greatly magnified since the joints represent the only work which is done in the field. Moreover, the various pre-assembled subsystems must connect within planned tolerance limits or significant construction problems will result—even though each subsystem in itself may be of the highest quality. Another problem unique to industrialized building is the design of the ground-building interface. This problem may be more apparent during construction than during use, but is nonetheless critical for housing modules which are brought intact to the site and placed on preconstructed foundations.

Modifications in Functional Performance Measures

Secondly, useful functional performance comparisons necessitate the introduction of ordinal scales. In the cases of physical phenomena (e.g., the foot-candles of illumination delivered by a given lighting system), or accounting representations of cost (capital costs, maintenance costs) objective measurements can be made of each phenomenon and the result can be expressed in cardinal (everyday numbers) terms. More subjective phenomena, such as the appearance, "delight" and other measures of functional performance associated with a building present greater measurement difficulties. New measurement procedures are therefore needed. The proposed method is based on the premise that most Army personnel live and work in more than one facility during their careers. Because of this fact, a person will always be able to compare at least two facilities with respect to some standard or level of performance. In this way, it is feasible to compare most of the alternative types of structures in each facility category.

All comparisons are made on a pair-wise basis, with the result being that, for example:

$A \succ B$ where " \succ " indicates "is preferred to." This preference relation can be assumed to be transitive. That is, if $A \succ B$ and $B \succ C$, then it is permissible to deduce that $A \succ C$.

Testing many pairs of facilities, a list ranking them on the basis of some performance factor can be obtained, (e.g., a listing in the form $A \succ B \succ C \succ \dots \succ J$, where each letter corresponds to a specific facility type.)

Hence, if any innovative facility (industrialized building) is introduced into use, the personnel involved can be polled to obtain the ranking of the new facility (or subsystem) with respect to existing types.

To demonstrate this method, suppose that there are two office lighting systems which are equally satisfactory in terms of life costs, intensity of illumination and other objectively measurable factors, and that it is desired to compare the degree to which they satisfy a requirement of building users for an adequate luminous environment.

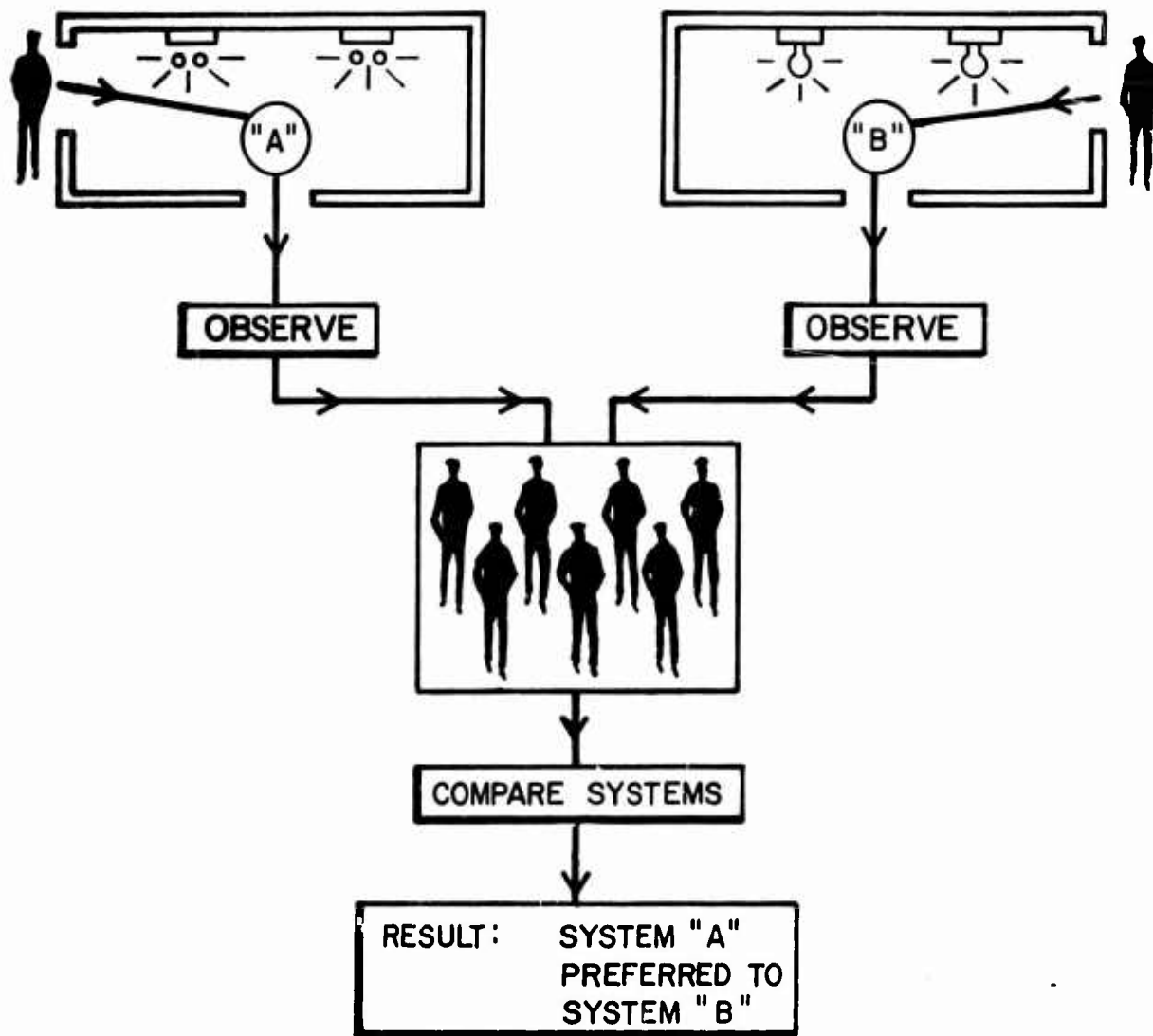
One possible method of testing user satisfaction is illustrated in Figure 37. Test installations of the two systems would be prepared in rooms which are identical in every other respect. A group of subjects, selected to represent the ultimate users of the type of facility in question would then be asked to spend time in each room performing tasks comparable to those to be performed in the type of facility in question. Each subject would finally be asked to express a preference for system "A" or system "B." A result such as "70 percent of the group tested prefers system 'A'" could then be used as a basis for subsequent design and policy decisions.

A Military Environment is particularly amenable to such evaluations because:

1. Generic plans are widely used, therefore there is a large sample of highly comparable buildings.
2. Similar operations are repeated frequently, therefore there is a large sample of highly comparable use situations.
3. The population of the Army is selected from a narrow range of the total population, therefore differences among separated groups of subjects will tend to be less than in a typical civilian population. This increases the likelihood that any two groups of Army personnel (say, clerks on Base A and clerks on Base B) will apply similar expectations of performance to the buildings in which they work.
4. At any given point in time (plus or minus a few years) it does seem safe to assume that a sufficiently large sample of subjects will apply a sufficiently constant level of expectation to any aspect of building, so that the method described is accurate enough to be useful.

Modifications in Cost Performance Accounting Procedures

Thirdly, costs incurred over the life of a facility (in the form of initial costs, maintenance and operating costs) are inadequately measured under current Army Building Inventory procedures. Rather, Cost data is aggregated over all facility types on a per square foot basis without specification of the particular nature of the buildings or the past maintenance procedures followed in the upkeep of the buildings. Such data is worthless for comparative or analytical purposes.



SUBJECTIVE EVALUATION -- RANKING SYSTEMS BY
DIRECT COMPARISON

FIGURE 37

If the total building performance, and hence, cost performance, of industrialized buildings is to be measured, careful descriptive monitoring of building life cycle costs for extended periods of time must replace current cost reporting formats.

Indeed, the detailed collection and tabulation of cost data on all physical aspects of a particular building for a period of time in excess of twenty years is mandatory for the successful implementation of life-cycle costing procedures for all Military Buildings.

DATA COLLECTION FORMATS

The most significant requirement for data collection formats is that they be so explicit and unambiguous that the possibility for subjective interpretation is minimized. Data are useless if they cannot be compared numerically. They must therefore be collected according to the measures specified in Table 5.

Formats used to survey the subjective assessments of buildings by their users will have to be developed especially for each study undertaken. Examples are given for a very simple set of forms in Appendix F. They are designed specifically to aid in the evaluation of industrialized barracks buildings.

Formats for the collection of physical performance data will be drawn from the testing literature. Again the example given in Appendix F is directed specifically to the evaluation of industrialized barracks.

The format shown in Appendix F for the collection of maintenance and repair data will be applicable to any study of in-use performance. Since this aspect of data collection, performed by the Facilities Director is by far the most detailed and time consuming part of the survey procedure, it appears desirable to model it on existing record-keeping procedures. The Work Order (DA Form 2700), shown in Exhibit 1, is the model for the proposed Maintenance and Repair Report Form. The Work Order is now filled out in the office of the Facilities Director for each maintenance and repair task to be performed. It states:

1. a description of the deficient component, and the task to be performed.
2. shop(s) to perform work
3. labor hours (estimate)
4. labor cost (estimate)
5. material cost (estimate)
6. equipment cost (estimate)

A collection of work orders covering a sample period would be an adequate source of information on maintenance and repair cycle lengths and maintenance and repair costs if the following changes were instituted in record-keeping procedures:

1. Institute a consistent coding of work according to subsystem. Ultimately, this consistent coding would be applied to all documents concerning building, including contract documents (plans and specifications), Building Information Schedules,* building regulation and work orders. Only if work orders were coded according to the system used in other descriptive documents would a speedy and orderly system of information retrieval be possible.
2. Include probable cause of deficiency in work order, so that when a problem was identified which required the development of corrective procedures, causes could be found.
3. Include on records actual job costs as well as estimated job costs.
4. Maintain accessibility to records for a suitable length of time. Currently, because of the volume of paperwork involved, these records are kept active for one year, stored for two or three years more, and then discarded. Even without ADP, it should be possible to keep records of the appropriate key indicators of performance for a selected sample of buildings, for an indefinite period. The necessity to reduce the number of key indicators and the size of the sample as much as possible is obvious.

*Currently from AR 210-20 (to be supplanted by the IFS).

Table 5
Building Performance Data Summary

| CATEGORY OF PERFORMANCE | | | MEASURE OF PERFORMANCE | | UNIT OF MEASURE | | | | | |
|-------------------------|-----------------------|-----------------------|------------------------|------------------------------|----------------------------|-------------------|-------------|---------------|--|--|
| | | | user need satisfaction | numeric performance standard | maintenance & repair cycle | replacement cycle | annual cost | instance cost | | |
| FUNCTIONAL PERFORMANCE | physical environment | visual environment | 1* | | | | | | | |
| | | acoustic environment | 1 | | | | | | | |
| | | thermal environment | 1 | | | | | | | |
| | | olfactory environment | 1 | | | | | | | |
| | flexibility | | 1 | | | | | | | |
| PRODUCT PERFORMANCE | building fabric | structure | | 2,3 | 14 | 15 | | | | |
| | | exterior wall | | 3 | 14 | 15 | | | | |
| | | interior partitions | | 3,4,5,6 | 14 | 15 | | | | |
| | | roof/ceiling | | 3,4,5,6 | 14 | 15 | | | | |
| | | floor/ceiling | | 3,4,7 | 14 | 15 | | | | |
| | building services | plumbing | | 3,8 | 14 | 15 | | | | |
| | | HVAC | | 5,8,9,10,11 | 14 | 15 | | | | |
| | | electrical | | 12,13 | 14 | 15 | | | | |
| COST PERF. | operations | | | | | | 16 | | | |
| | maintenance & repairs | | | | | | | 16 | | |

*Numerals refer to notes below.

NOTES TO TABLE 5

1. See Table 6 "Measurements of Functional Performance."
2. deflection (inches)
3. Sound Transmission Class (STC)
4. reflectance (percent measured by Baumgartner type reflectometer)
5. Impact Insulation Class (IIC)
6. Noise Reduction Coefficient (NRC)
7. Gloss (measured by 60 degree Gardner Gloss Meter)
8. Noise Level (NC)
9. temperature (°F)
10. air motion (fpm)
11. humidity (RH)
12. light intensity (foot candles)
13. brightness (footlamberts)
14. The frequency of maintenance and repairs required in similar use situations will vary with the materials and design of comparable subsystems or components. It can serve, therefore, as a measure of the appropriateness of various materials and designs. Frequency of maintenance and repair, and costs of maintenance and repair, can be used to determine the annual cost of maintaining the performance and/or appearance of any subsystem or component at a satisfactory level. This is taken to be the most useful and reliable index of durability, reliability and maintainability. Other methods of evaluation, such as visual inspection of surfaces, etc., fall prey to dependence on subjective judgment, as well as lacking a direct link to owning cost.
15. The monitoring of replacement cycles can lead to the development of obsolescence criteria, which are virtually absent from current standards for building performance.

Table 6
Measurements of Functional Performance*

| | | SUBJECT | | SUBSYSTEM AFFECTING SATISFACTION | | | | | | | |
|-----------|-----------------------------|-------------|---------------|----------------------------------|---------------|--------------|---------------|---------------------|----------|------|------------|
| | | direct user | indirect user | structure | exterior wall | roof/ceiling | floor/ceiling | interior partitions | plumbing | HVAC | electrical |
| USER NEED | good lighting conditions | X | | | | 0 | 0 | 0 | | | X |
| | good appearance | X | | X | X | X | X | X | 0 | 0 | X |
| | good acoustical environment | X | | 0 | 0 | X | X | X | 0 | X | 0 |
| | bodily comfort | X | | | X | X | | | | X | |
| | odor control | X | | | | | | | | X | |
| | short-term flexibility | X | X | | | X | X | X | X | X | X |
| | long-term flexibility | | X | | | X | X | X | X | X | X |
| | expendability | | X | X | X | X | 0 | 0 | 0 | 0 | 0 |

*/x/-primary effect
 /0/-secondary effect
 / /-no effect

| | | | | | | | |
|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------|----------------------------------------------------------------------------------------------------------------------------|-------------|------------------------------------|----------|------------|------------|
| WORK ORDER (Repairs and Utilities) <small>(DA Form 420-5)</small> | | BUILDING OR FACILITY NO. Bldg 50, PSF | | SERIAL NUMBER <i>PR 26/4/11</i> | | | |
| <input checked="" type="checkbox"/> INDIVIDUAL JOB ORDER <input type="checkbox"/> STANDING OPERATION ORDER | | | | DATE 3 February 1971 | | | |
| REQUESTED BY (Name) Mr D Abrams | | ORGANIZATION Heating, FAE | | TELEPHONE NO. 4939 | | | |
| APPROVED BY <i>[Signature]</i> | | SOO EFFECTIVE DATE FROM: TO: | | | | | |
| BRIEF DESCRIPTION AND LOCATION Remove & replace big 4 booster water heater for rinse cycle 180° water; re-pair additional water heater riser; remove & replace venting. DA Form 2702 attached to I.J.O. for Heating. | | SUMMARY OF ESTIMATE | | | | | |
| | | SHOP | LABOR HOURS | LABOR COST | MAT COST | EQUIP COST | TOTAL COST |
| | | HEATING | 32.00 | 218.00 | 275.00 | 12.00 | 505.00 |
| | | METAL WORK | 6.00 | 44.00 | 15.00 | 4.00 | 63.00 |
| | | | | | | | |
| PRIORITY U R G E N T | | TOTAL | 38.00 | 262.00 | 290.00 | 16.00 | 568.00 |
| MAN HOUR WORKING ESTIMATE (For continuation use plain white paper) | | | | | | | |
| SHOP | ACTIVITY CODE | JOB PHASE DESCRIPTION | | | | EST HRS | |
| <i>24</i> | <i>19-40</i> | <div style="border: 1px solid black; padding: 10px; width: fit-content; margin: auto;"> EXHIBIT 1 </div> | | | | | |
| <div style="position: relative; width: 100%; height: 100%;"> <div style="position: absolute; top: 50%; left: 50%; transform: translate(-50%, -50%);"> <p>FIGURE 38</p> <p><i>Slip meter # 27.00</i></p> </div> </div> | | | | | | | |

INTERPRETATION OF DATA

Any of the performance data described above can be used to generate frequency distribution curves, hereafter referred to as "performance profiles." These will plot numbers of cases (buildings) against the appropriate measure of performance. This could be any of the measures identified in Table 5.

To illustrate, let us plot a performance profile for Noise Reduction (Fig. 39).^{*} Assume that this is a plot of data obtained from a representative sample of sleeping spaces in enlisted mens barracks constructed with conventional methods and materials.

In the absence of an objective standard for acoustic isolation, the acceptability of a new building (with respect to acoustic isolation) can be determined by locating its performance level on the performance profile of existing buildings (Fig. 40). Most simply, certification in the absence of objective standards of performance could be defined as performance superior to a certain percentage of the existing stock of buildings.

In a similar fashion, the performance of one class of buildings may be compared to the performance of one or more classes of buildings, for the purpose of certification (Fig. 41).

There are obvious drawbacks to using the stock of existing buildings as a simple touchstone of acceptability. For example, many buildings currently in use are beyond their prime, and obsolete in one sense, or more. It is desirable to identify means of locating thresholds of acceptability.

It must be recognized that the techniques suggested are merely ways of marshalling information, rather than formulae which automatically establish a value. This is due to the fact that the relative weighting of cost and performance is always shifting as priorities are redefined. In time of war, for example, speed of construction may be the highest priority, with cost and longevity receding in importance. In times of scarcity, first cost may outweigh all other considerations. In a situation where the Army depends on attracting peacetime volunteers, environmental benefits to the direct users of buildings become more important.

It is possible to correlate two curves: performance profile and satisfaction of user needs, by relating them both to performance level (Fig. 42). In this case a sharp rise in the satisfaction of user needs identifies a point (or narrow range) in the performance level which may serve to define the threshold of acceptability. This comparison becomes important when a high priority is assigned to user need satisfaction.

Assume on the other hand that control of total owning cost is the highest priority. It is possible to compare the performance profile to annual owning cost (a function of cost per year to maintain performance, capital cost and lifespan). This is shown in Figure 43. Here again, a narrow range can be identified on which small increases in cost cease to give great increases in performance level.

It is the fortunate case that many times the shapes and values of cost curves and user need satisfaction curves are similar to the degree that they lead to the same conclusion. For example, it is possible that a sharp increase in costs and a sharp leveling off of benefits occurs at about the same level of performance. Whether or not this is the case, when priorities are identified it should always be possible to define thresholds of acceptability, or standards. These thresholds of acceptability serve two functions:

1. They can be used to set performance standards.
2. They can be used to evaluate and refine existing standards.

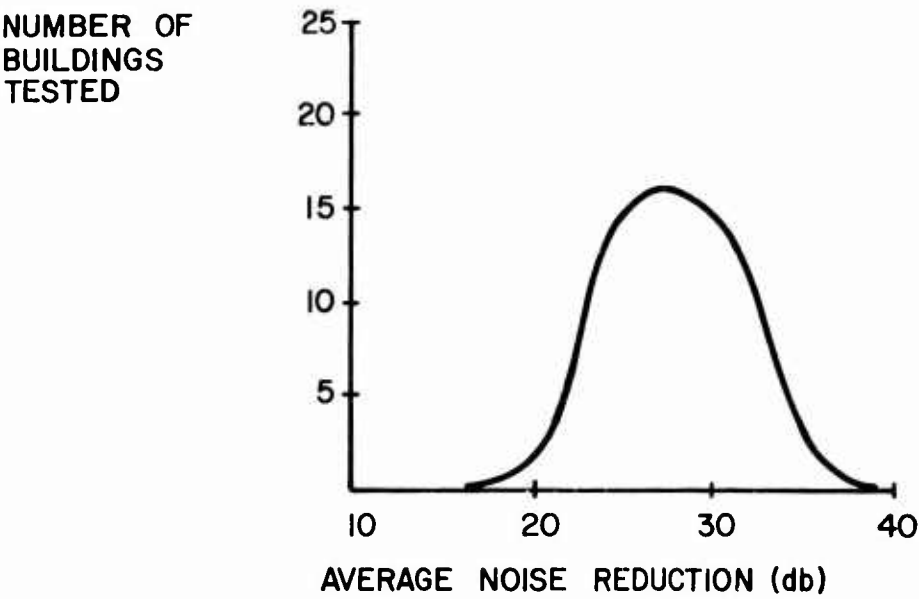
The method of display described above may be used for all three types of survey data: assessments or user satisfaction, physical measurements and cost-time data.

FEEDBACK PROCEDURES

The digested data of in-use appraisal can be put to the following uses:

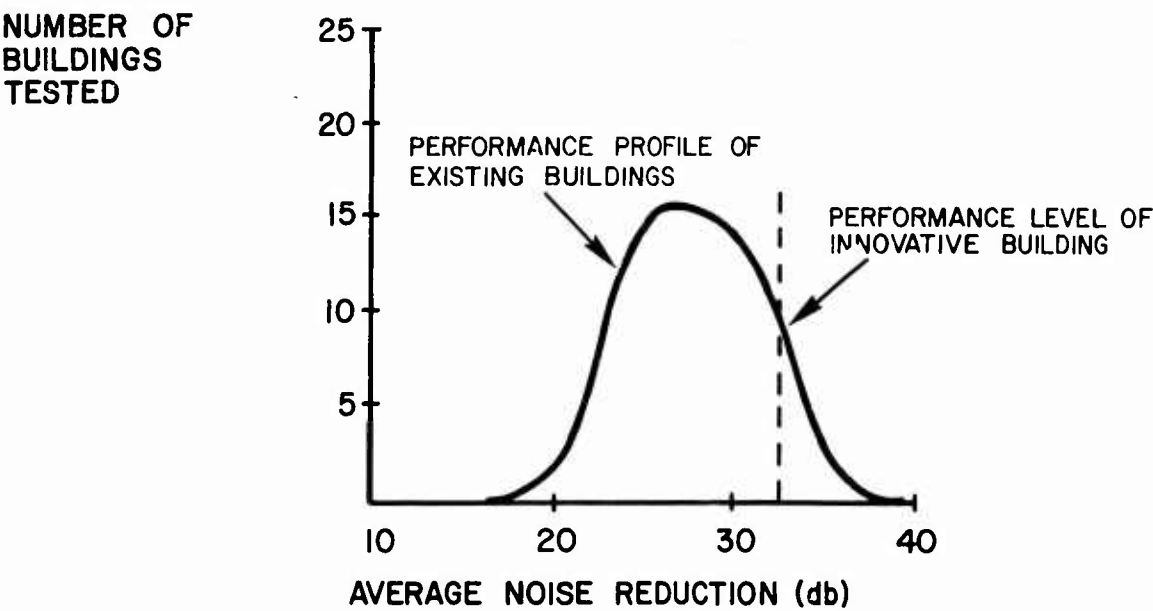
1. Certification. The first and most obvious application of in-use appraisals of buildings is to certify the quality of innovative hardware and/or procedures, and hence to serve as a direct guide in the design of new buildings. Thus, for example, a class of building excluded from current specifications might be certified as satisfactory if so indicated by in-use appraisal of prototypes.

^{*}The numeric values upon which the following illustrations are based are arbitrary, and are intended merely to illustrate a procedure. They are not intended to represent the actual performance levels of existing buildings.



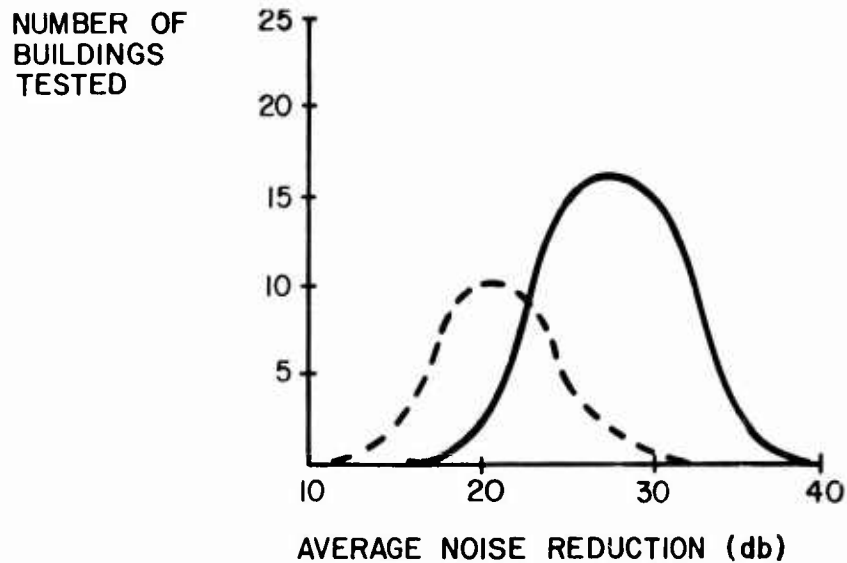
PERFORMANCE PROFILE -- ATTENUATION OF AIRBORNE SOUND BETWEEN SLEEPING SPACES IN CONVENTIONAL BARRACKS

FIGURE 39



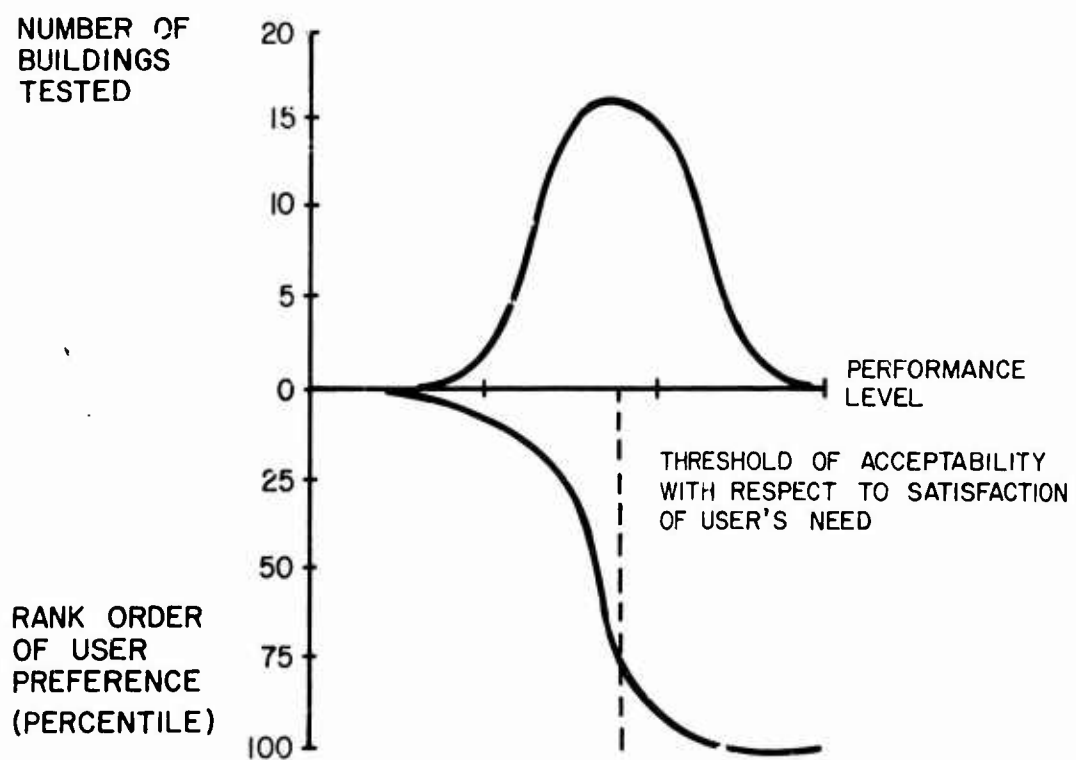
PERFORMANCE LEVEL OF AN INNOVATIVE BUILDING COMPARED TO PERFORMANCE PROFILE OF EXISTING BUILDINGS

FIGURE 40



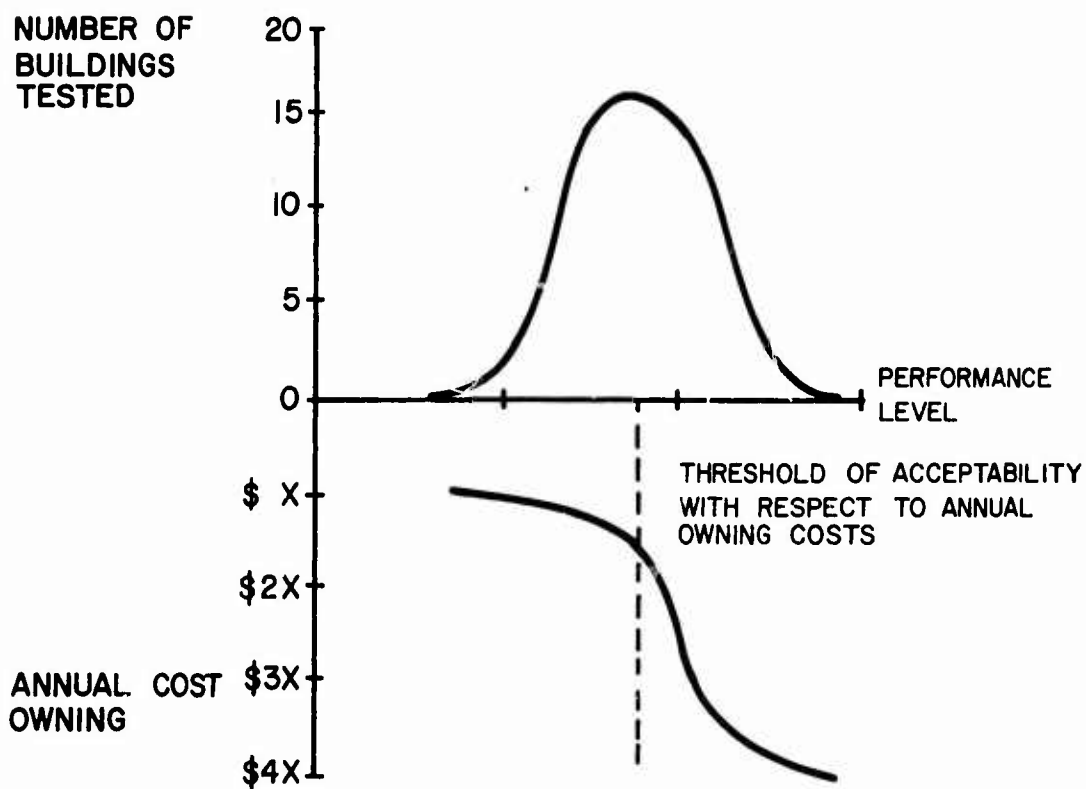
PERFORMANCE PROFILES OF CONVENTIONAL AND INDUSTRIALIZED BUILDINGS COMPARED

FIGURE 41



PERFORMANCE PROFILE COMPARED TO CURVE OF USER NEED SATISFACTION PLOTTED AGAINST PERFORMANCE LEVEL

FIGURE 42



PERFORMANCE PROFILE COMPARED TO CURVE OF ANNUAL OWNING COST PLOTTED AGAINST PERFORMANCE LEVEL

FIGURE 43

It must be recognized that the process of certification by the approval of particular solutions has inherent limitations. Although it is intended to provide a mechanism for innovation with a minimum amount of risk, it tends to make acceptance of innovation slow and difficult. The time required to test an innovation in use will always produce a significant delay between its appearance and its availability for widespread application.

Such certification still remains extremely valuable. Precedents for it exist in several well developed European systems for evaluation and approval of innovations in buildings, pioneered by the French with their Agrément system.

2. **Setting of Standards.** The second application of in-use appraisals of buildings is to aid in the establishment of objective standards of performance. The starting point for the development of these explicit expectations of performance must be the level of performance obtained from existing buildings. Unless this current level of performance has been carefully and extensively measured, performance standards can have no firm basis, in reality.

3. **Testing Against Standards.** The third application of in-use appraisals of buildings is to determine whether any objective standards of performance which exist (at the time of measurement) are being met. This comparison of actual performance to expected performance serves two functions:

a. It establishes compliance (or non-compliance) with the standard in question.

b. It can aid in the evaluation and refinement of the standard itself. For example, suppose that a standard for sound isolation between adjacent office spaces exists at STC 40.

Suppose then that it is determined by a suitably controlled examination of an adequate sample of buildings in use that acoustic isolation is deemed satisfactory by the users when spaces are separated by a barrier field-rated at STC 25. This would indicate that the standard in question is excessively high, and that economies are possible in construction with no impairment of function if the standard is reduced.

4. **Problem Solving.** Fourth, and not incidentally, the very process of in-use appraisal will call to attention correctable deficiencies in the buildings which are examined, and hence in other buildings of the class which they represent.

Solutions to recurring deficiencies which are noted in the survey data will be proposed by OCE and communicated to Post Engineers of relevant installations. In many cases these will be problems which might be solved only in local and isolated cases, if at all.

CONCLUSIONS

1. The problem of reporting engineering and/or construction deficiencies in buildings as a means to the correction of deficiencies and to the elimination of their causes, is, in a sense, sidestepped by the proposal that such reporting can be replaced by the careful monitoring of a sample of buildings which statistically represent the entire building population of the Army.

It does not appear to be necessary (nor would it be easy) to monitor deficiencies for every building. If a manageable sample of buildings is chosen for study, highly detailed data can be gathered and analyzed which will present a statistically accurate picture of the performance of the Army's entire stock of buildings. The correct definition of this sample is perhaps the most critical task to be dealt with in designing a system for the in-use appraisal of buildings.

2. "Predicted performance" (to which "actual performance" is compared) is seen to lie in objective standards (where possible), but also in comparison to current practice at any point in time.

3. The methods of analysis described in this chapter can be applied to any innovation in building, whether or not it fits the narrow definition given for "industrialized building." As time goes on and new issues arise for evaluation, new key indicators will be defined, and the size of the sample of buildings surveyed will grow. As the use of automatic data processing techniques can be expected to increase, the gradual growth of the surveyed sample should cause no technical problems.